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Improved and New Roofing for Military Construction

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Long Term Field Test Results of Experimental EPDM and PUF Roofing

by

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Experimental roofs of single-ply ethylene-propylene-diene monomer (EPDM) and sprayed-in-place polyurethane foam (PUF) were installed during 1979 and 1980 at Fort Benning, GA and Fort Lewis, WA. This research documents the long term results of a field test program to evaluate the effects of aging/weathering on the EPDM and PUF materials and the repairability of the surfaces. An EPDM membrane provides a satisfactory, water-tight roof. Aging is directly related to the local climate. Current repair techniques for EPDM are satisfactory when proper materials and procedures are used. PUF roof should give satisfactory service if repairs are properly made and the surface is periodically recoated as the original coating wears away.

It is recommended that authorized roofing personnel be used or that installation personnel be trained by the roofing manufacturer to maintain and repair each type of roof system installed. Specifications for PUF roofing should be expanded to include urethane/Hypalon coating. Additionally, studies should be done to evaluate the ability of newly applied foam to bond to that which is already in place, and to determine how long the bond can be expected to last.

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FOREWORD

This work was performed by the Engineering and Materials Division (EM) of the U.S. Army Construction Engineering Research Laboratory (USACERL) for the U.S. Army Engineering and Housing Support Center (USAHSC) under Project 4A762731AT41, "Military Facilities Engineering Technology"; Task A, "Facilities Planning and Design"; Work Unit 044, "Improved and New Roofing for Military Construction." The Technical Monitor during the majority of this research was Chester Kirk. The current Technical Monitor for this work unit is Mike Smith (CEHSC-FB-S).

Appreciation is expressed to the personnel at Forts Benning and Lewis for taking samples from the test roofs; to Mr. Bernard V. Jones and Mr. Vernon L. Kuehn of the U.S. Bureau of Reclamation for performing the mechanical and physical tests on the material samples; and to Mr. Brian K. Young for reducing and analyzing the recorded data. Dr. Robert Quattrone is Chief of USACERL-EM. The Technical Editor was Gloria J. Wienke, USACERL Information Management Office.

LTC E.J. Grabert, Jr. is Commander of USACERL and Dr. L. R. Shaffer is Director.



A-1

CONTENTS

	Page
SF 298	1
FOREWORD	2
LIST OF TABLES AND FIGURES	4
1 INTRODUCTION	7
Background	7
Objective	7
Approach	8
Mode of Technology Transfer	8
2 DESCRIPTION OF TEST PROGRAM	9
Construction of Test Roofs	9
Test Program	9
3 PHYSICAL AND MECHANICAL PROPERTY CHANGES	15
Climate Comparisons Between Fort Lewis and Fort Benning	15
EPDM Property Changes	15
Description of Coatings for PUF	26
PUF Roofing Property Changes	27
Significance of Data	35
4 RESULTS OF VISUAL OBSERVATIONS	38
First Annual Inspections	38
Second Annual Inspections	39
Third Annual Inspections	39
Fourth Annual Inspections	40
Fifth Annual Inspections	40
Sixth Annual Inspections	41
Seventh Annual Inspections	42
Followup Inspection at Fort Benning	42
Discussion of Visual Inspections	43
5 CONCLUSIONS AND RECOMMENDATIONS	45
Conclusions	45
Recommendations	45
METRIC CONVERSION TABLE	46
REFERENCES	46
DISTRIBUTION	

TABLES

Number		Page
1	PUF Test Characteristics	13
2	EPDM Test Characteristics	14
3	Climatological Normals, Means, and Extremes for Seattle-Tacoma, WA, Airport	16
4	Climatological Normals, Means, and Extremes for Columbus, GA, Metropolitan Airport	17
5	Initial Properties of EPDM Roofing Materials	19
6	EPDM Roofing - Physical Properties for Initial and Aged Characteristics at Fort Benning	21
7	EPDM Roofing - Physical Properties for Initial and Aged Characteristics at Fort Lewis	22
8	Initial Properties of PUF Roofing Materials	28
9	PUF Roofing - Physical Properties for Initial and Aged Characteristics at Fort Benning	31
10	PUF Roofing - Physical Properties for Initial and Aged Characteristics at Fort Lewis	32

FIGURES

1	EPDM Roofs, Cross Sections	10
2	PUF Roofs, Cross Sections	10
3	Building Selected for EPDM Roofing at Fort Benning	11
4	Building Selected for PUF Roofing at Fort Benning	11
5	Building Selected for EPDM and PUF Roofing at Fort Lewis	12
6	Mean Daily Solar Radiation - United States Annual	18
7	EPDM Tensile Strength	23
8	EPDM Elongation	23

FIGURES (Cont'd)

Number		Page
9	EPDM Hardness	24
10	EPDM Abrasion Loss	25
11	EPDM Water Absorption	25
12	EPDM Seam Strength - Shear	26
13	EPDM Seam Strength - Peel	27
14	PUF Compressive Strength	33
15	PUF Tensile Strength - Interlaminar	33
16	PUF Density	34
17	PUF Water Absorption	34
18	PUF Impact Strength	36
19	PUF Indentation Strength	36
20	PUF Coating Adhesion	37

LONG TERM FIELD TEST RESULTS OF EXPERIMENTAL EPDM AND PUF ROOFING

1 INTRODUCTION

Background

Most Army facilities use conventional roofing systems (such as built-up roofing) that are sometimes expensive and complicated to construct. These conventional roofing systems are often comparatively short-lived, resulting in high life-cycle roofing costs which are difficult for already overburdened Army operation and maintenance budgets to absorb. Therefore, the U.S. Army Engineering and Housing Support Center has asked the U.S. Army Construction Engineering Research Laboratory (USACERL) to attempt to identify alternative, easy-to-install roofing systems that can improve the performance of Army roofing while reducing life-cycle costs.

Previous work identified and evaluated alternative roofing systems that would be less susceptible to installation error or misapplication and would not be as sensitive to storage, handling, and weather considerations.¹

Experimental roofs of single-ply ethylene-propylene-diene monomer (EPDM, a synthetic rubber) sheet and sprayed-in-place polyurethane foam (PUF) with elastomeric coatings were installed during 1979 and 1980 at Fort Benning, GA, Fort Knox, KY, and Fort Lewis, WA. Construction of these systems was described in *Construction of Experimental Roofing*,² and the results of tests of the first 2 years of service life were described in *Field Test Results of Experimental EPDM and PUF Roofing*.³ Annual sampling and testing of the samples continued until 1986 at Fort Benning and Fort Lewis (Fort Knox was dropped from the program in 1981).

Objective

The objective of this report is to document the long term results of a field test program to evaluate the EPDM and PUF systems, from both the effect of the climate on aging/weathering of the materials and the reparability of the membranes by both trained contractor personnel and inadequately trained installation personnel.

¹ E. Marvin, et al., *Evaluation of Alternative Reroofing Systems*, Interim Report, M-263/ADA071578 (U.S. Army Construction Engineering Research Laboratory [USACERL], June 1979); M.J. Rosenfield, *An Evaluation of Polyvinyl Chloride (PVC) Single-Ply Membrane Roofing Systems*, Technical Report M-284/ADA097931 (USACERL, March 1981); M.J. Rosenfield, *Evaluation of Sprayed Polyurethane Foam Roofing and Protective Coatings*, Technical Report M-297/ADA109696 (USACERL, November 1981).

² M.J. Rosenfield and D.E. Brotherson, *Construction of Experimental Roofing*, Technical Report M-298/ADA109595 (USACERL, November 1981).

³ M.J. Rosenfield, *Field Test Results of Experimental EPDM and PUF Roofing*, Technical Report M-357/ADA147697 (USACERL, September 1984).

Approach

The following procedures were used to carry out the objective of this study:

1. Roof systems for a 10-year field evaluation were selected based on earlier USACERL studies.⁴
2. A test plan was developed using standard test methods published by the American Society for Testing and Materials (ASTM) and other tests developed by government agencies.
3. Test sites were selected.
4. Test guide specifications were developed.
5. Instrumentation systems were designed.
6. Construction of the test roofing systems was monitored.
7. Test data were collected for 7 years after construction.
8. Each roof was inspected visually once a year.

Mode of Technology Transfer

Information generated by this study will impact on Corps of Engineers Guide Specifications (CEGS) 07530, *Elastomeric Roofing (EPDM)*, and CEGS 07540, *Elastomeric Roofing, Fluid Applied*.

⁴E. Marvin, et al.; M.J. Rosenfield, March 1981; M.J. Rosenfield, November 1981.

2 DESCRIPTION OF TEST PROGRAM

Construction of Test Roofs

EPDM Roofs

Two EPDM roofs were constructed: one at Fort Benning, GA, and one at Fort Lewis, WA. Both are fully adhered, unballasted systems, with the membrane bonded to the insulation surface. The insulation is sufficient to give the roofing system an overall R-value of 20.

The system at Fort Benning consists of a fluted steel deck, 3 in.* of composite board insulation mechanically fastened to the deck, and 60-mil thick single-ply EPDM membrane. The system at Fort Lewis consists of a poured-in-place concrete roof deck, a one-ply vapor retarder of No. 43 asphalt-saturated and coated glass fiber base sheet installed in hot asphalt, 2-1/2 in. of rigid inorganic board stock with asphalt-saturated organic felt facer sheets installed in hot asphalt, and a 60-mil thick single-ply EPDM membrane. Figure 1 shows cross sections of the EPDM roofs.

PUF Roofs

Three PUF roofs were constructed: one each at Fort Benning, GA, Fort Knox, KY, and Fort Lewis, WA. (Fort Knox was dropped from the program in 1981 and no data will be presented.) The system at Fort Benning consists of a poured-in-place concrete roof deck, a two-ply vapor retarder of No. 15 asphalt-saturated organic felt, a minimum of 3-1/2 in. of sprayed PUF, and a minimum of 20 mils of a single-component, moisture-cured silicone coating, applied in two coats with granules in the second coat.

The system at Fort Lewis consists of a poured-in-place concrete roof deck, one ply of No. 43 asphalt-saturated and coated glass fiber base sheet in hot asphalt, a minimum 3 in. of sprayed PUF, and a coating consisting of a base coat of a two-component polyurethane elastomer and a top coat of chlorosulfonated polyethylene with granules. The minimum thickness was specified as 20 mils but was actually determined to be 10 mils. Figure 2 shows the cross sections of those PUF roofs.

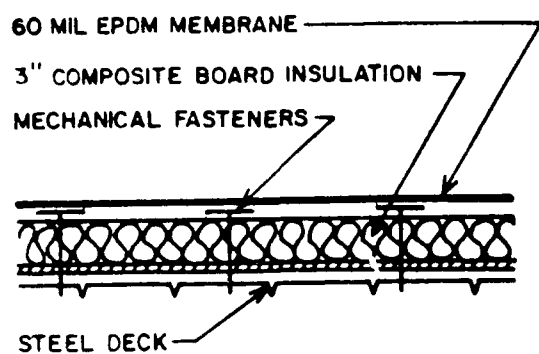
Figures 3 through 5 show the roof plans of the buildings selected for EPDM and PUF at Forts Benning and Lewis. Construction of these systems is described in *Construction of Experimental Roofing*.⁵

Test Program

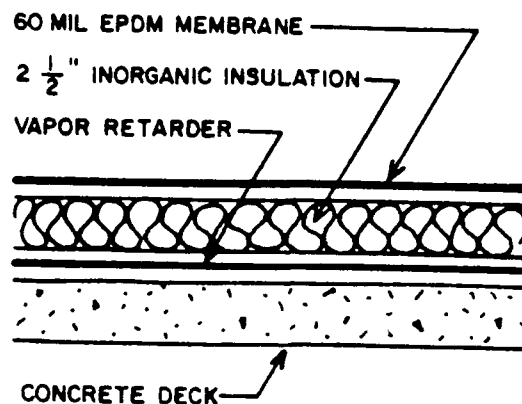
The test program was designed to determine how weathering would change the mechanical and physical characteristics of the two systems as well as their repairability. Properties selected for study were those deemed essential to successful performance of the materials in a roof assembly. ASTM standards were used when possible to determine these properties. If no ASTM test method could be found, tests developed by the U.S. Bureau of Reclamation (USBR) or the U.S. Naval Civil Engineering Laboratory (NCEL) were used.

* A metric conversion table is provided on page 46.

⁵ M.J. Rosenfield and D.E. Brotherson.

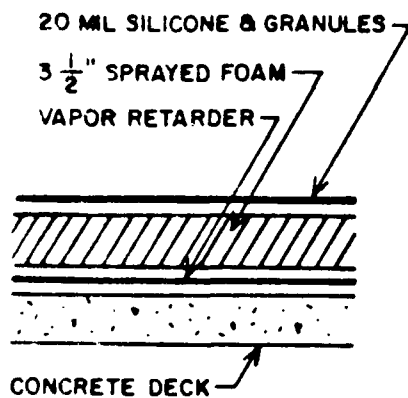


FORT BENNING

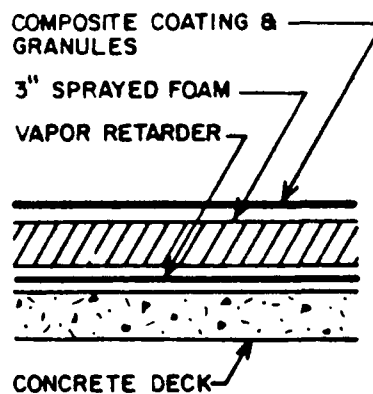


FORT LEWIS

Figure 1. EPDM roofs, cross sections.

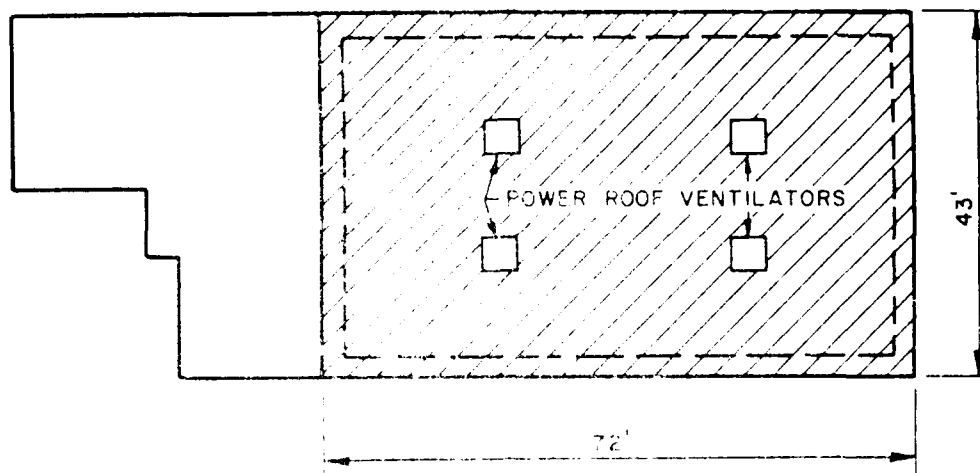



FORT BENNING



FORT LEWIS

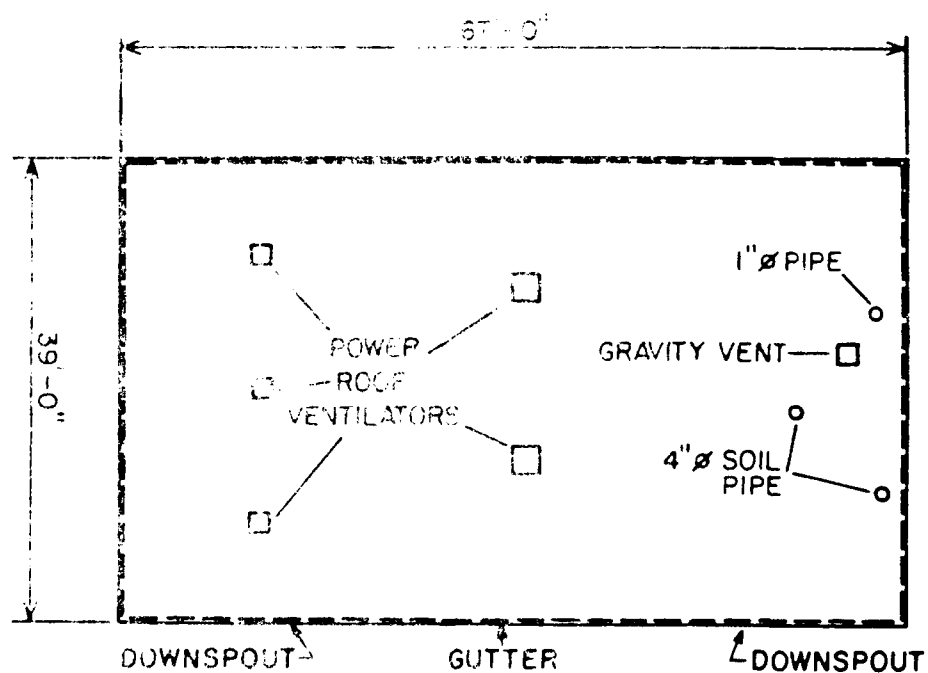
Figure 2. PUF roofs, cross sections.



LEGEND
 INDICATES AREA WITH
 NEW EPDM ROOF

ROOF PLAN - BLDG 2823

Figure 3. Building selected for EPDM roofing at Fort Benning.



ROOF PLAN - BLDG 2806

Figure 4. Building selected for PUF roofing at Fort Benning.

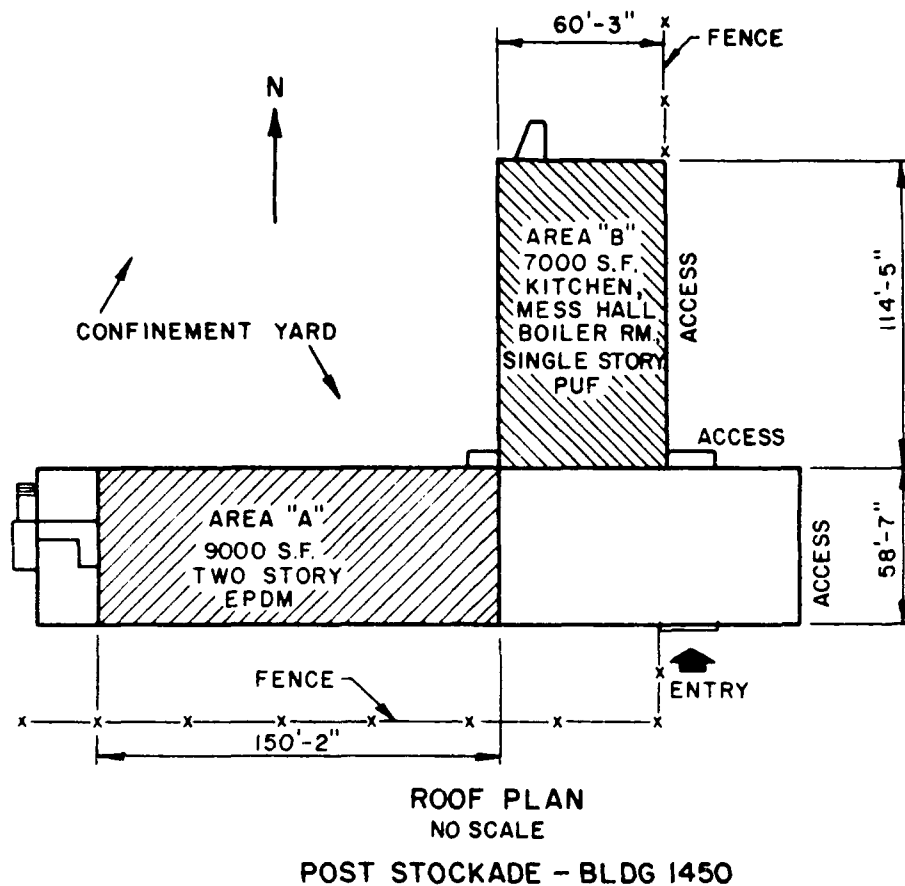


Figure 5. Building selected for EPDM and PUF roofing at Fort Lewis.

The initial set of tests was designed to establish the mechanical and physical characteristics of the materials at the time of application. Subsequent tests were originally scheduled every 6 months for 2 years, and once a year for 8 more years to establish a pattern of performance or to note changes in properties; however, the tests were concluded after 7 years because researchers were no longer able to obtain proper samples from the EPDM roof at Fort Benning and because repairs to the PUF roof had failed.

Each test consisted of analyzing five samples and averaging the results. One sample was cut near each corner of the roof and one near the center so that the results would have minimal dependence on the location. In addition to the laboratory tests, visual inspections were made annually to check for changes in appearance, loss of adhesion of EPDM membrane or PUF coating, blistering, cracking, pinholing, loss of granules, or any evidence of mechanical damage from foot or equipment traffic, unauthorized attachments or penetrations, or natural phenomena such as hail.

Tables 1 and 2 list the PUF and EPDM characteristics, respectively, of interest to this study.

Table 1
PUF Test Characteristics

Tests at Beginning of Exposure Program		Remarks
Property	Test Method	"Property" refers to physical properties of interest.
Foam		
Water Vapor Transmission	ASTM C 355	The amount of movement or dimensional change must not exceed the coating capacity.
Dimensional Stability	ASTM D 2126	
Closed Cell Content	ASTM D 2856	
Coating		
Thickness	USBR Test	These tests will establish "baseline" for coating for comparison with later tests taken from field-exposed samples.
Brittle Temperature	ASTM D 2137	
Test at Beginning and Intermittently During Program		
Foam		
Foam Density	ASTM D 1622	The material must not deteriorate or lose density. Urethane foams are sensitive to moisture. Moisture may enter from below (condensation) or above (leakage).
Water Absorption	ASTM D 2842	
Tensile Strength	USBR Test	
Compressive Strength	ASTM D 1621	
Coating		
Water Vapor Transmission	ASTM E 96	
Glass Transition	ASTM D 3418	
Foam With Applied Coating		
Indentation Hardness	USBR Test	The foam and coating must be capable of resisting foot traffic and other mechanical abuses, including continued resistance to hail and falling objects.
Adhesion	NCEL Test	
Impact Resistance (with applied coating)	USBR Test	
Field Monitoring		
Visual Inspection		Check for adhesion loss, blistering, cracking, flaking, peeling, pinholing, hail damage, and severe cracking or erosion.
Weather Data		
Temperature		
Humidity		
Solar Radiation		
Wind Speed and Direction		

Table 2

EPDM Test Characteristics

Tests at Beginning of Exposure Program

Property	Test Method	Remarks
Heat Aging	ASTM D 573	"Property" refers to physical properties of interest. This group of tests is used to provide a means of predicting weather performance.
Accelerated Aging	ASTM D 2565	
Brittleness	ASTM D 2137	
Dimensional Stability	ASTM D 1204	

Tests at Beginning and Intermittently During Program

Abrasion Loss	ASTM D 3389	These are tests to establish the basic physical characteristics typical of roof membranes. Any changes in these characteristics during service could signal aging, deterioration, and reduction of lifetime expectancy. Abrasion resistance is necessary if the roof will experience regular foot traffic; seam strength is essential in one-ply systems; changes in hardness indicate a loss of plasticizer and resistance to mechanical damage; absorption and permeability are necessary characteristics if the membrane is used over existing roofing systems with possible moisture entrapment; D 1876 and D 412 tests should be run at 70°F.
Seam Strength	ASTM D 1876 & D 882, Method A	
Tensile Strength	ASTM D 412	
Ultimate Elongation	ASTM D 412	
Hardness	ASTM D 2240	
Water Resistance		
Absorption	ASTM D 570	
Permeability	ASTM E 96, Proc. B	
Ozone Resistance	ASTM D 1149	
Glass Transition	ASTM D 3418	

Field Tests and Monitoring

Weather Data	These measurements are needed to correlate with strain and temperature measurements.
Temperature	
Humidity	
Solar Radiation	
Wind Speed and Direction	

Periodic Field Observations

Visual Inspection	This type of inspection with photographs will provide a record of physical changes and/or appearance.
Nondestructive Moisture Measurement	

3 PHYSICAL AND MECHANICAL PROPERTY CHANGES

Climate Comparisons Between Fort Lewis and Fort Benning

The Fort Lewis area is characterized by equable temperatures, a pronounced though not sharply defined rainy season and considerable cloudiness, particularly during the winter months. The prevailing southwesterly circulation keeps average winter daytime temperatures between 40 and 50 °F and nighttime readings between 30 and 40 °F (Table 3). During the summer months, the nighttime readings consistently range from 50 to 55 °F. A typical summer afternoon would have readings between 70 and 85 °F. The hot spells last only a few days. The agreeable temperatures and the light precipitation characteristic of the warm season give Fort Lewis a very pleasant summer climate. More than 75 percent of the yearly rainfall occurs from October through March.

The Fort Benning climate is determined primarily by its latitude, and the proximity of the Gulf of Mexico and the Atlantic Ocean. The driest season is autumn, with the greatest rainfall in midsummer. Fort Benning has warm, humid summers (averages 74 days with temperatures above 90 °F and short mild winters (Table 4). The flow of moist air from the Gulf over the warm land surface results in frequent afternoon thunderstorms during the summer. Cold snaps usually occur from mid-November to mid-March, with daytime temperatures almost always rising to above freezing. Relative humidity averages are moderately high, as would be expected from its location in relation to the Gulf and Ocean.

Comparing the two locations, Fort Lewis has a relatively stable temperature range throughout the year, while Fort Benning has warmer temperatures in the summer and about the same temperatures as Fort Lewis in the winter. Fort Benning also averages more than twice the number of clear sunny days than does Fort Lewis (113 to 54). Fort Lewis averages more cloudy days (228 to 151). This results in a higher heat load and ultraviolet radiation on the roofs at Fort Benning, and the correspondingly higher roof degradation associated with the increased solar exposure. The mean daily solar radiation is about 413 Langleys at Fort Benning, compared to 300 Langleys at Fort Lewis (Figure 6). Fort Benning averages more than eight times the number of thunderstorms and associated severe weather than does Fort Lewis (58 to 7) and heavier annual rainfall, mostly in the summer. The rainfall and severe weather at Fort Benning is significant. The hot Georgia sun expands the membrane and flashing which then cools down and shrinks with the rain. Also, because the annual rainfall in Georgia is higher, more problems associated with ponding could occur.

EPDM Property Changes

Initial EPDM Properties

It is often assumed that EPDM is the same material, regardless of its source; however, this is not the case. Proportions of ethylene and propylene and the diene used may vary, depending on availability, price, and formula. Thus, even the products of one company may differ. However, all EPDM membranes should meet ASTM D 4637-87⁶ and ANSI/RMA IPR-1-1985⁷ National Standards. The EPDM materials delivered to the two sites are the products of the same manufacturer. The initial test values shown in Table 5 are averaged from several tests on the materials delivered to each location. The range of values is also stated.

⁶ *Standard Specification for Vulcanized Rubber Sheet Used in Single Ply Roof Membrane*, ASTM D 4637-87 (American Society for Testing and Materials [ASTM], 1987).

⁷ *Rubber Sheets for Use in Roofing Applications, Minimum Requirements for Non-Reinforced Black EPDM*, ANSI/RMA IPR-1-1985 (American National Standards Institute, 1985).

Table 3

Climatological Normals, Means, and Extremes for Seattle-Tacoma, WA, Airport

Temperatures (F)							Precipitation in Inches					Mean Number of Days				
Normal			Extremes				Water Equivalent					Sunrise to Sunset			THUNDERSTORMS	90° & ABOVE
MONTH	HIGH	LOW	HIGH	YEAR	LOW	YEAR	AVERAGE	HIGH	YEAR	LOW	YEAR	CLEAR	PARTLY CLOUDY	CLOUDY		
J	43.9	34.3	64	1981	0	1950	6.04	12.92	1953	0.86	1949	3	3	25	*	0
F	48.8	36.8	70	1968	1	1950	4.22	9.11	1961	1.58	1977	3	3	22	*	0
M	51.1	37.2	72	1947	11	1955	3.59	8.40	1950	0.57	1965	3	6	22	1	0
A	56.8	40.5	85	1976	29	1975	2.40	4.19	1978	0.33	1956	3	7	20	1	0
M	64.0	46.0	93	1963	28	1954	1.58	4.76	1948	0.35	1947	4	10	17	1	*
J	69.2	51.1	96	1955	38	1952	1.38	3.90	1946	0.13	1951	5	8	17	1	*
J	75.2	54.3	98	1979	43	1954	0.74	2.39	1983	TRACE	1960	10	10	11	1	1
A	73.9	54.3	99	1981	44	1955	1.27	4.59	1975	0.01	1974	9	9	13	1	1
S	68.7	51.2	94	1981	35	1972	2.02	5.95	1978	TRACE	1975	8	8	14	1	*
O	59.5	45.3	82	1980	28	1949	3.43	8.95	1947	0.72	1972	4	7	20	*	0
N	50.3	39.3	74	1949	6	1955	5.60	9.69	1963	0.74	1976	3	4	23	1	0
D	45.6	36.3	63	1980	6	1968	6.33	11.85	1979	1.37	1978	2	3	26	*	0
YR	58.9	43.9	99	AUG 1981	0	JAN 1950	38.60	12.92	JAN 1953	TRACE	SEP 1975	57	78	230	7	3

*Less than one-half.

REF: "Climate of the States," Volume 2, Gale Research Company, Book Tower, Detroit, MI, 1987.

Table 4

Climatological Normals, Means, and Extremes for Columbus, GA, Metropolitan Airport

Temperatures (F)							Precipitation in Inches					Mean Number of Days					
Normal			Extremes				Water Equivalent					Sunrise to Sunset			THUNDERSTORMS	90° & ABOVE	
MONTH	HIGH	LOW	HIGH	YEAR	LOW	YEAR	AVERAGE	HIGH	YEAR	LOW	YEAR	CLEAR	PARTLY CLOUDY	CLOUDY			
J	56.9	35.4	83	1949	3	1966	4.52	10.22	1947	0.87	1954	8	6	17	1	0	
F	60.6	37.0	83	1962	11	1973	4.52	9.41	1961	1.22	1951	8	6	14	2	0	
M	68.6	43.9	89	1982	16	1980	5.96	12.51	1952	1.40	1967	9	7	15	4	0	
A	77.4	51.9	92	1970	28	1950	4.50	11.67	1953	0.86	1967	10	8	12	5	*	
M	83.8	60.2	97	1962	39	1963	4.44	8.45	1959	0.22	1962	9	11	11	7	6	
J	89.4	67.6	104	1978	44	1956	4.16	10.83	1967	1.24	1979	8	12	10	9	16	
J	91.1	71.0	104	1977	59	1967	5.50	13.24	1971	1.74	1957	5	13	13	13	20	
A	90.8	70.5	102	1983	57	1952	4.02	10.07	1977	0.96	1956	8	13	10	9	20	
S	86.0	65.9	99	1957	38	1967	3.59	6.94	1951	0.42	1955	10	8	12	4	10	
O	77.0	53.1	96	1954	24	1952	2.07	8.09	1964	0.00	1963	15	6	10	1	1	
N	67.0	42.7	86	1961	10	1950	3.06	12.45	1948	0.31	1956	2	6	12	1	0	
D	59.5	37.2	82	1977	4	1962	4.75	9.39	1953	0.43	1955	10	6	15	1	0	
YR	75.6	53.0	104	JUNE 1978	3	JAN 1966	51.09	13.24	JUL 1971	0.00	OCT 1963	112	102	151	58	74	

*Less than one-half.

REF: "Climate of the States," Volume 2, Gale Research Company, Book Tower, Detroit, MI, 1987.

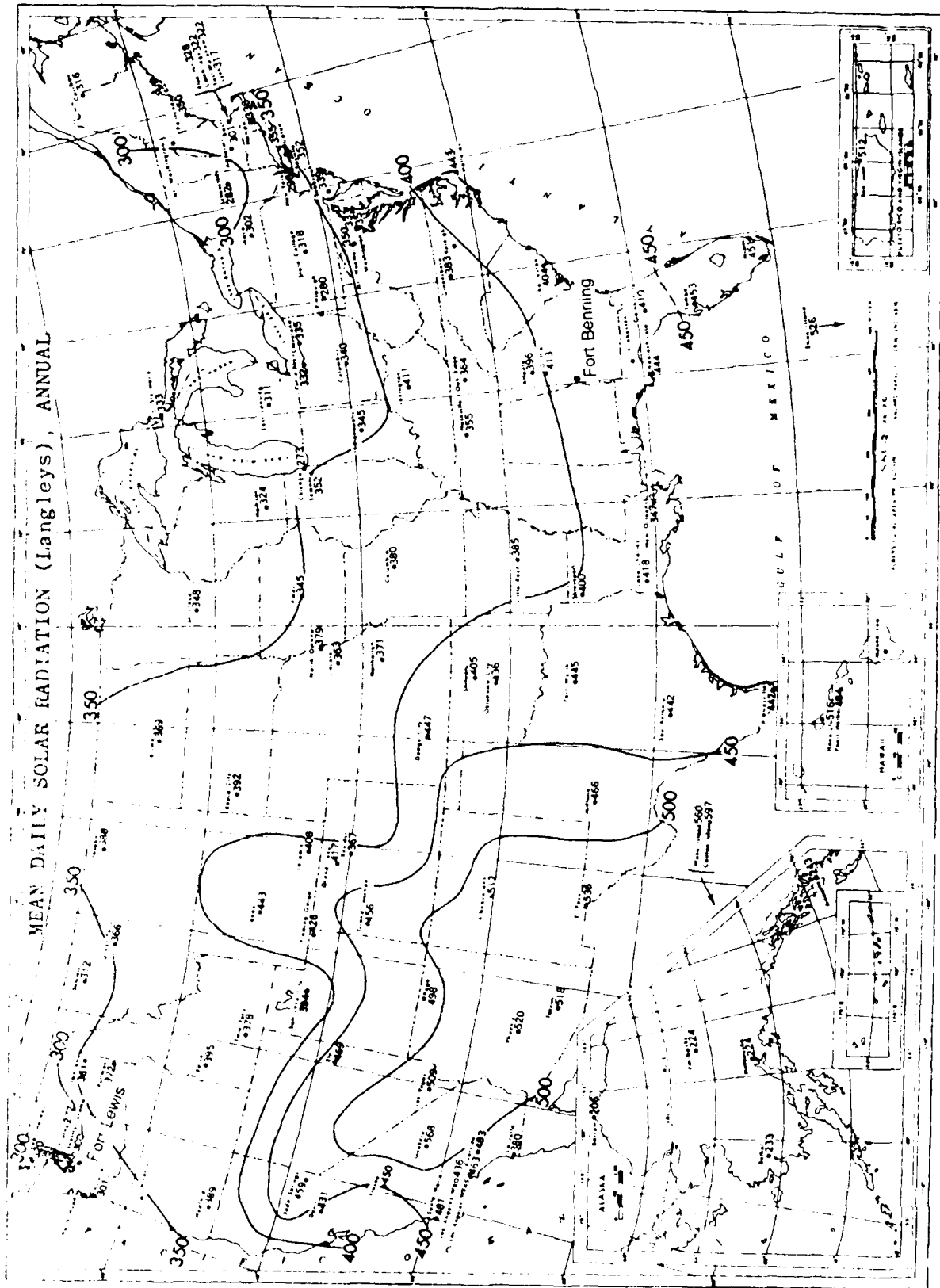


Figure 6. Mean daily solar radiation - United States annual.

Table 5

Initial Properties of EPDM Roofing Materials

Property	Specified Value	Test Method		Fort Benning	Fort Lewis
Tensile strength (lb/sq in.)	1400	Longitudinal	ASTM D 412	Average Range	1585 1445 to 1705
		Transverse		Average Range	1525 1405 to 1650
Elongation (percent)	300	Longitudinal	ASTM D 412	Average Range	540 475 to 640
		Transverse		Average Range	580 530 to 640
Hardness (Shore "A")	50 to 70		ASTM D 2240	Average Range	58 56 to 60
Ozone resistance	No cracks		ASTM D 1149	No cracks	No cracks
Water absorption (weight %)			ASTM D 570	Average Range	+0.5 0.26 to 0.72
Vapor transmission (perm-mils)	2.0		ASTM E 96 Procedure B	Average Range	3.6 2.4 to 5.3
Glass transition temperature (°F)	-50 max		ASTM D 3418	Average Range	-60 -62 to -58
Abrasion loss (grams/1000 rev.)			ASTM D 3389	Average Range	0.19 0.15 to 0.22
Seam strength (lb/in. width)		Peel	ASTM D 1876	Average Range	0.8 0.4 to 2.0
		Shear	ASTM D 882 (A)	Average Range	18.0 14.9 to 19.7
Low temperature brittleness (°F)	-75		ASTM D 2137	Average Range	-80 -79.1 to -80.5
Dimensional stability 24 hours at 100°F % change)		Longitudinal		Average Range	0.0 0.0 to 0.0
		Transverse	ASTM D 1204	Average Range	-0.1 -0.1 to -0.1
Heat aging (longitudinal direction)		Tensile strength		Average Range	102 100 to 107
		Elongation	ASTM D 573	Average Range	61 57 to 66
Percent of original physical properties		100% modulus		Average Range	193 178 to 205
Xenon arc exposure		Period exposed	ASTM D 2565	3-13-81/4-28-82 Operating hours 4024	
Outdoor exposure		Period exposed Surface change Months		USBR 8-80 to 4-83 Surface graying - no significant change	32

The mechanical properties of the delivered materials (tensile strength, elongation, and hardness) all exceed the values that were specified, which are the minimums stated in the manufacturer's literature. These initial values indicate good-quality rubber sheet. However, the field seam peel strength at Fort Benning is very low, with an average of 0.8 lb/in. of width. The peel strength at Fort Lewis is 2.5 lb/in., which is considered more typical of expected values. The shear strength at Fort Benning is 18 lb/in. of width, or only 20 percent of the sheet tensile strength. The seam shear strength at Fort Lewis is 28.7 lb/in., or 29 percent of the sheet strength. According to the manufacturer, the shear strength of the seam should be at least 30 percent of the sheet strength. Observations of the seam area after separation indicated that the sheet was not completely cleaned of its talc coating before the cement was applied.

Of the physical properties, only the brittleness, ozone resistance, and water vapor permeability were specified by the manufacturer. Water absorption and abrasion loss were determined so that the effect of aging on these properties could also be measured. The brittleness value was exceeded and the ozone resistance was met, but a difference was noted for the water vapor permeability, which was specified as 2.0 perm-mils. According to the manufacturer, this is neither a maximum nor a minimum, but is the actual value as determined in the laboratory. The measured value at Fort Benning of 0.06 perm calculates to 3.6 perm-mils while the Fort Lewis value of 0.03 perm calculates to 1.98 perm-mils. Any value less than 1 perm is considered to be a vapor retarder, and the manufacturer describes this product as impermeable. The manufacturer's determination was conducted by Procedure BW of ASTM E 96-80; the results of the USACERL test were obtained from Procedure B of the same test method. Test method E 96 states that "agreement should not be expected between results obtained by different methods,"⁸ so even though the measured values are not the same, they are of the same order of magnitude and are close. What is significant is the change that occurs in the value over time.

Changes in EPDM Properties With Time

Tables 6 and 7 outline the changes in physical and mechanical properties of the EPDM membrane at Forts Benning and Lewis, respectively. Three points are worth noting. First, tests indicate the material has the normal tendency of rubber products to show slight increases/decreases in mechanical properties during exposure to heat. For these roofs, tensile and abrasion values increased between 1 and 3 years after installation and then showed a gradual decrease. Second, changes in these mechanical properties are readily measured and, even after 7 years at Fort Benning, the properties were no less than 90 percent of the manufacturer's published specifications in 1979. Third, the EPDM membrane at Fort Benning aged more rapidly than the membrane at Fort Lewis. This difference is most evident in the changes in elongation and hardness. The major reason for this difference is most likely the level of solar radiation (UV degradation). Other factors include material formulation and contaminants.

Tests by others⁹ indicate that the EPDM roof materials display increased tensile strength, reduced elongation properties, and increased hardness after accelerated aging. Results of the field test (shown in Figures 7, 8, and 9) indicate similar effects of natural aging. There was an initial increase in tensile properties after exposure of 6 months at Fort Benning, but the succeeding tests indicate a gradual return

⁸ *Standard Test Methods for Water Vapor Transmission of Materials*, ASTM E 96-80 (American Society for Testing and Materials, October 31, 1980).

⁹ R. Dupuis, et al., "Temperature Induced Behavior of New and Aged Roof Membranes," *Proceedings, Second International Symposium on Roofs and Roofing* (September 1981).

Table 6

**EPDM Roofing--Physical Properties for Initial and Aged Characteristics
Fort Benning**

PROPERTY		TEST METHOD	AGE (IN MONTHS)									
			0	6	12	18	24	30	48	72	84	
TENSILE STRENGTH (LB/SQ IN)	ASTM D 412	RANGE	1445 TO 1705	1610 TO 1790	1580 TO 1680	1607 TO 1698	1590 TO 1655	1516 TO 1654	1567 TO 1606	1539 TO 1608	1266 TO 1309	
		AVERAGE	1585	1660	1650	1650	1630	1627	1591	1566	1287	
ELONGATION (PERCENT)	ASTM D 412	RANGE	475 TO 640	440 TO 505	470 TO 510	410 TO 431	395 TO 465	335 TO 420	310 TO 350	300 TO 350	320 TO 340	
		AVERAGE	540	470	494	421	430	381	336	320	332	
HARDNESS (SHORE A)	ASTM D 2240	RANGE	56 TO 60	60 TO 62	60 TO 62	61 TO 62	62 TO 64	61 TO 62	73 TO 76	73 TO 78	73 TO 75	
		AVERAGE	58	61	61	62	63	62	75	76	75	
OZONE RESISTANCE	ASTM D 1149	NO CRACKS	NO CRACKS	NO CRACKS	NO CRACKS	NO CRACKS	NO CRACKS	NO CRACKS	NO CRACKS	NO CRACKS	NO CRACKS	
WATER ABSORPTION (WEIGHT %)	ASTM D 570	RANGE	0.26 TO 0.72	0.38 TO 0.77	0.58 TO 0.76	0.80 TO 0.98	0.81 TO 0.97	0.76 TO 0.92	1.03 TO 1.15	1.19 TO 1.34	---	
		AVERAGE	0.5	0.6	0.7	0.9	0.9	0.9	1.1	1.3	---	
VAPOR TRANSMISSION (PERM-MILS)	ASTM E 96 PROCEDURE B	RANGE	2.4 TO 5.3	1.7 TO 1.8	1.2 TO 1.2	1.4 TO 1.8	2.1 TO 2.4	1.7 TO 1.9	---	---	---	
		AVERAGE	3.6	1.8	1.2	1.6	2.3	1.8	---	---	---	
ABRASION LOSS (GRAMS/1000 REV)	ASTM D 3389	RANGE	0.15 TO 0.22	0.13 TO 0.18	0.11 TO 0.15	0.07 TO 0.09	0.07 TO 0.16	0.08 TO 0.11	---	---	---	
		AVERAGE	0.19	0.16	0.13	0.08	0.10	0.09	0.19	0.19	---	
SEAM STRENGTH PEEL (LB/IN WIDTH)	ASTM D 1876	RANGE	0.4 TO 2.0	---	---	---	1.3 TO 2.1	---	---	1.1 TO 1.8	---	
		AVERAGE	0.8	---	---	---	1.6	---	---	1.3	---	
SEAM STRENGTH SHEAR (LB/IN WIDTH)	ASTM D 382(A)	RANGE	14.9 TO 19.7	---	---	---	22.5 TO 37.0	---	---	24.0 TO 28.8	---	
		AVERAGE	18.0	---	---	---	27.0	---	---	26.1	---	
GLASS TRANSITION TEMPERATURE (°F)	ASTM D 3418	RANGE	-62 TO -58	-62 TO -54	-62 TO -58	-62 TO -56	-62 TO -54	-54 TO -53	---	---	---	
		AVERAGE	-60	-60	-60	-60	-58	-54	---	---	---	

Table 7

**EPDM Roofing--Physical Properties for Initial and Aged Characteristics
Fort Lewis**

PROPERTY	TEST METHOD	AGE (IN MONTHS)							
		0	12	18	24	48	60	84	
TENSILE STRENGTH (LB/SQ IN)	ASTM D 412	RANGE 1640 TO 1845	1518 TO 1879	1793 TO 1858	1713 TO 1810	1478 TO 1714	1650 TO 1720	1410 TO 1552	
	AVERAGE	1705	1710	1810	1761	1634	1691	1495	
ELONGATION (PERCENT)	ASTM D 412	RANGE 480 TO 540	424 TO 569	385 TO 425	425 TO 473	320 TO 450	380 TO 430	500 TO 540	
	AVERAGE	505	495	400	449	396	404	518	
HARDNESS (SHORE A)	ASTM D 2240	RANGE 56 TO 58	55 TO 60	52 TO 56	57 TO 61	68 TO 72	66 TO 70	60 TO 67	
	AVERAGE	57	57	54	59	69	69	65	
OZONE RESISTANCE	ASTM D 1149	NO CRACKS	NO CRACKS	NO CRACKS	NO CRACKS	NO CRACKS	NO CRACKS	NO CRACKS	
WATER ABSORPTION (WEIGHT %)	ASTM D 570	RANGE 0.34 TO 0.48	0.29 TO 0.35	0.35 TO 0.42	0.67 TO 0.81	0.57 TO 0.63	0.66 TO 0.78	0.90 TO 0.99	
	AVERAGE	0.4	0.3	0.4	0.7	0.6	0.7	0.9	
VAPOR TRANSMISSION (PERM-MILS)	ASTM D E 96 PROCEDURE B	RANGE 1.9 TO 2.0	1.8 TO 2.6	1.9 TO 2.5	1.6 TO 2.4	---	---	---	
	AVERAGE	2.0	2.4	2.2	2.0	---	---	---	
ABRASION LOSS (GRAMS/1000 REV)	ASTM D 3389	RANGE 0.17 TO 0.21	0.13 TO 0.17	0.11 TO 0.14	0.10 TO 0.13	---	---	0.18 TO 0.25	
	AVERAGE	0.19	0.14	0.13	0.11	0.21	---	0.21	
SEAM STRENGTH PEEL (LB/IN WIDTH)	ASTM D1876	RANGE 1.6 TO 4.3	1.8 TO 3.8	1.9 TO 3.4	1.5 TO 2.6	1.6 TO 2.2	1.0 TO 3.2	1.8 TO 2.0	
	AVERAGE	2.5	2.7	2.8	1.9	1.9	1.9	1.9	
SEAM STRENGTH SHEAR (13/IN WIDTH)	ASTM D 882(A)	RANGE 22.8 TO 34.0	23.2 TO 29.0	21.7 TO 28.2	21.8 TO 28.0	22.0 TO 27.6	22.2 TO 27.8	---	
	AVERAGE	28.7	26.0	25.0	24.2	24.6	25.7	---	
GLASS TRANSITION TEMPERATURE (°F)	ASTM D 3418	RANGE -66 TO -65	-59 TO -57	-62 TO -56	-60 TO -58	---	---	---	
	AVERAGE	-65	-58	-58	-59	---	---	---	

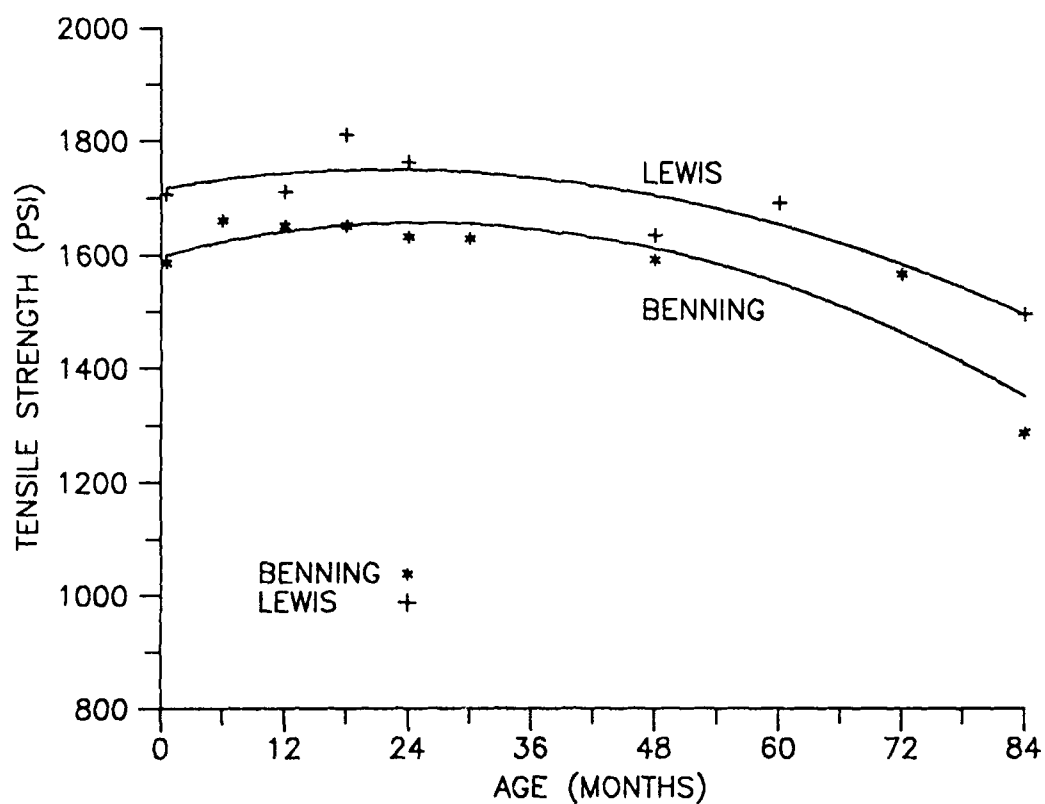


Figure 7. EPDM tensile strength.

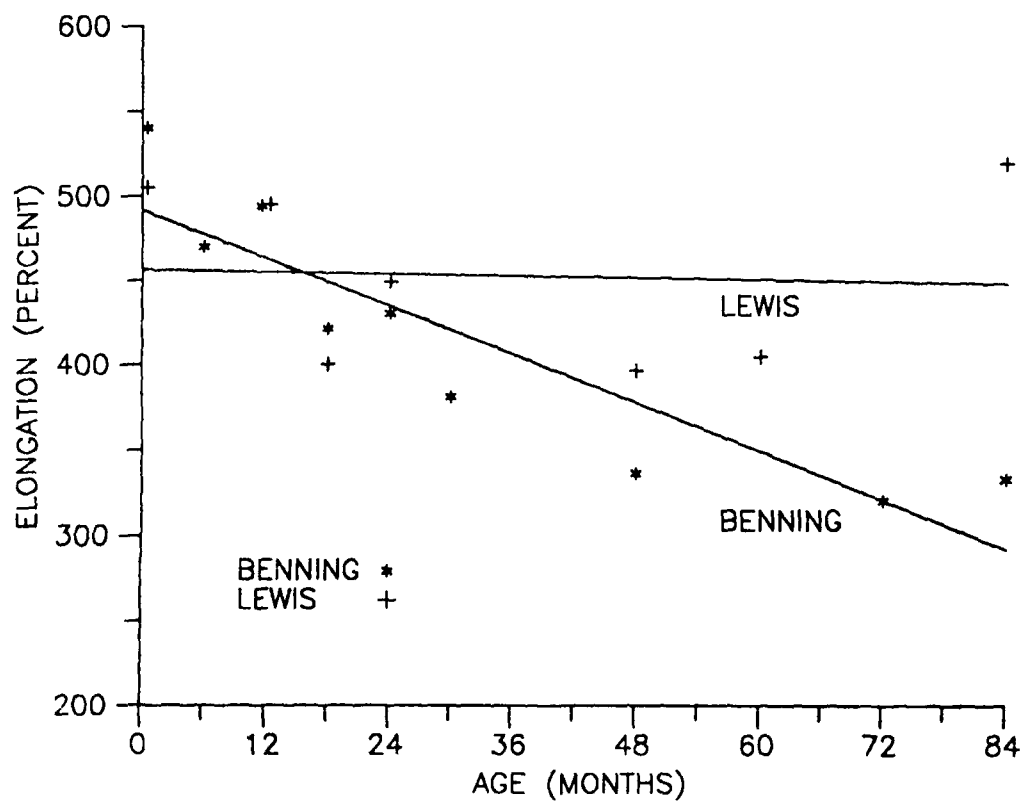


Figure 8. EPDM elongation.

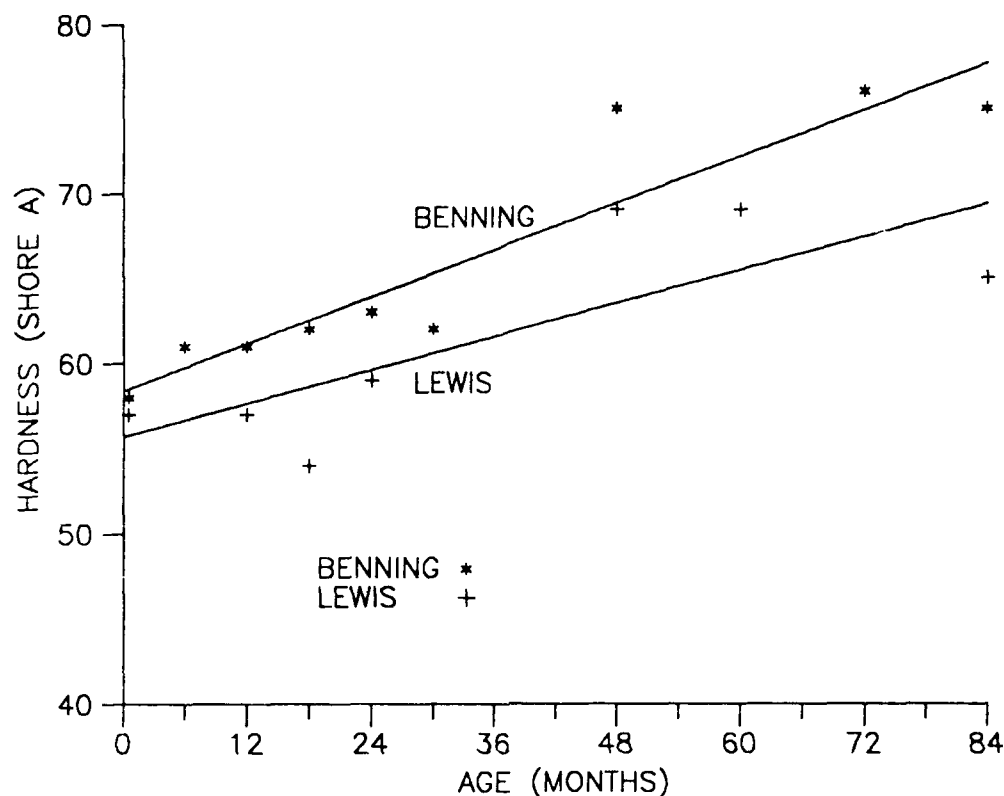


Figure 9. EPDM hardness.

to just below the original value after 6 years. At Fort Lewis, an increase was evident up to 18 months with a steady drop to just below the original value after 5 years. Decrease in elongation and increase in hardness indicated long term hardening of the EPDM at both locations. The abrasion loss (Figure 10) showed a steady increase after declining during the first 3 years. Water absorption (Figure 11) of the membrane at Forts Benning and Lewis steadily increased over time, but the change is so slight as to be essentially insignificant.

Seam strength testing was performed as scheduled for the system at Fort Lewis but not at Fort Benning due to poor sample conditions. The shear strength of the seam (Figure 12) decreased to a low of 24 lb/in. width after 2 years and stabilized. The peel strength (Figure 13) dropped from an initial value of 2.5 lb/in. width to 1.9 lb/in. after 2 years and stabilized. The seams lost 16 percent of their initial strength in shear and up to 24 percent of their initial strength in peel. The drop in peel strength at Fort Lewis apparently did not affect the performance of the seams. The seams at Fort Benning were initially very weak but show a substantial increase in both peel and shear strengths with time. At both locations, the system is fully adhered, so the strength of the seams is not as important as it would be if the membrane were either loose laid or mechanically fastened. An important result of these field tests was that the original seams at both locations maintained their watertight integrity, despite the aging of the membrane surfaces, except for one seam at Fort Benning.

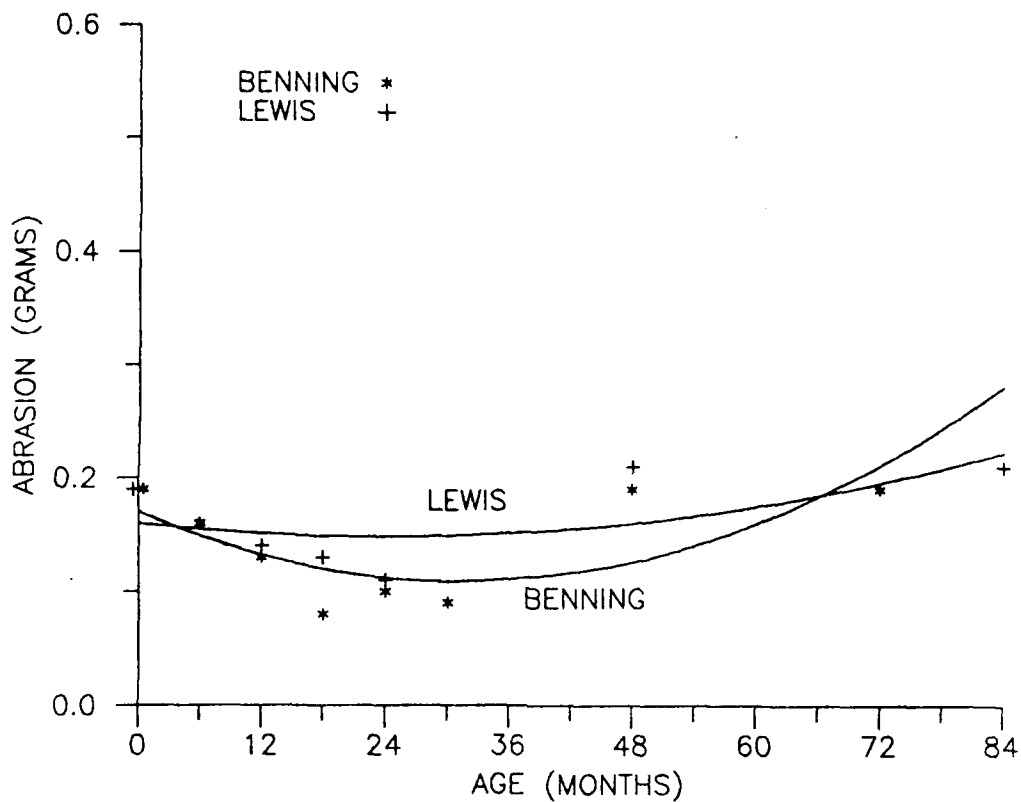


Figure 10. EPDM abrasion loss.

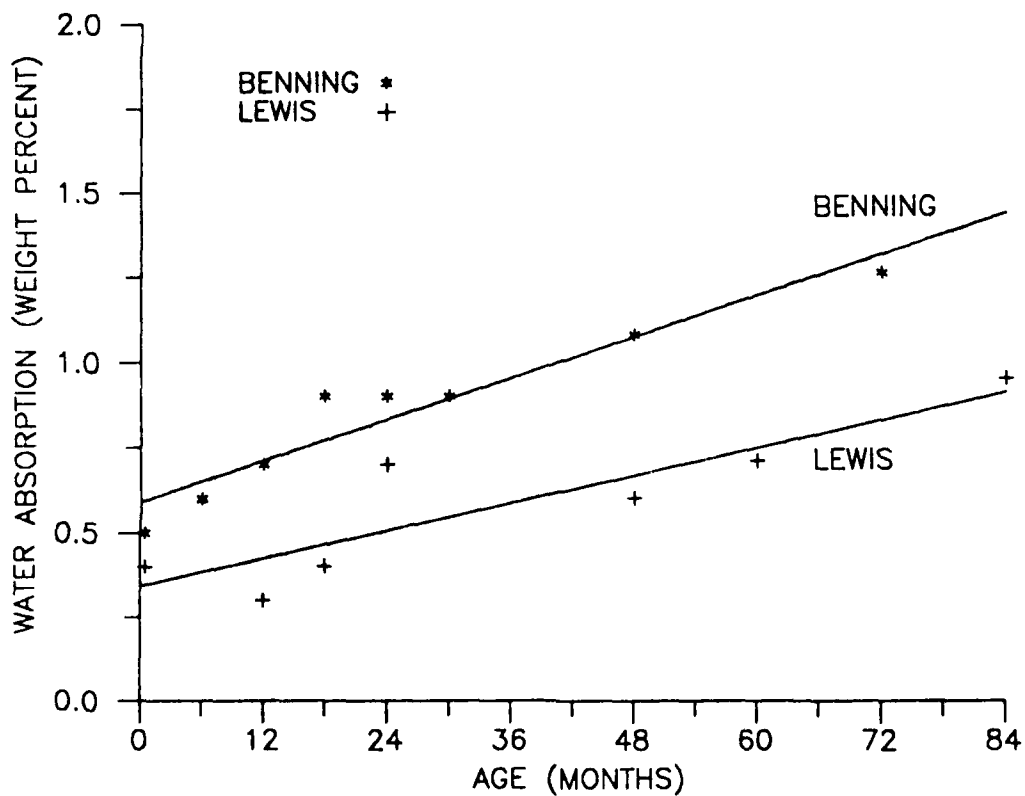


Figure 11. EPDM water absorption.

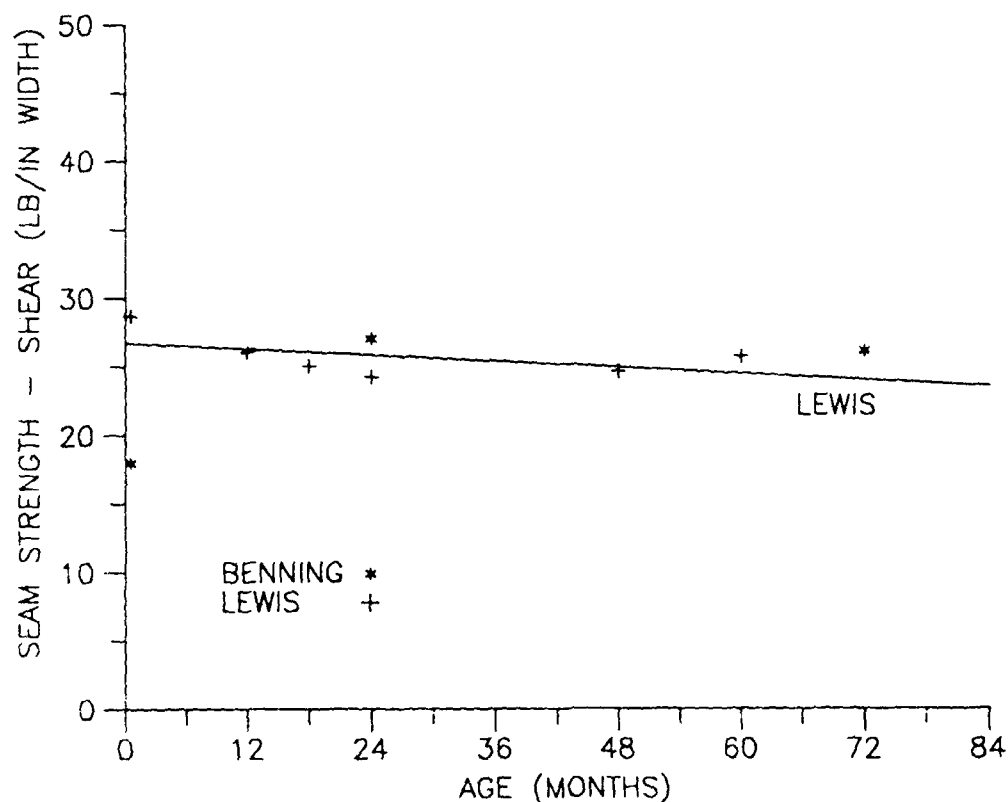


Figure 12. EPDM seam strength - shear.

Monitoring of the water vapor transmission and glass transition temperature was ended after the first 2-1/2 years due to the small amount of change exhibited in these properties and their relative insignificance. Since EPDM is not considered a "breathable" membrane, the change in water vapor transmission is not in itself important. Its significance is only apparent when viewed in the context of changes to the other properties. Also, the glass transition temperature range for EPDM (-53 to -66 °F) is far below the temperatures normally expected in the continental United States.

Description of Coatings for PUF

At the time of construction, CEGS 07540 limited the elastomeric coating for sprayed PUF roofing to silicone materials. Silicones are available in two forms: a two-component, catalyzed liquid that is mixed in the gun as it is sprayed, and a single-component, moisture-cured liquid that requires no mixing. These materials have demonstrated excellent retention of all necessary properties. Since that time, two-component catalyzed urethane coating has been added to the guide specification.

The urethane base coat/Hypalon* top coat system was selected to obtain a basis for evaluating a different coating. Each system included applying ceramic granules to the top coat while it was still fluid.

* Hypalon is a registered trademark of E. I. DuPont de Nemours and Co for their brand of chlorosulfonated polyethylene.

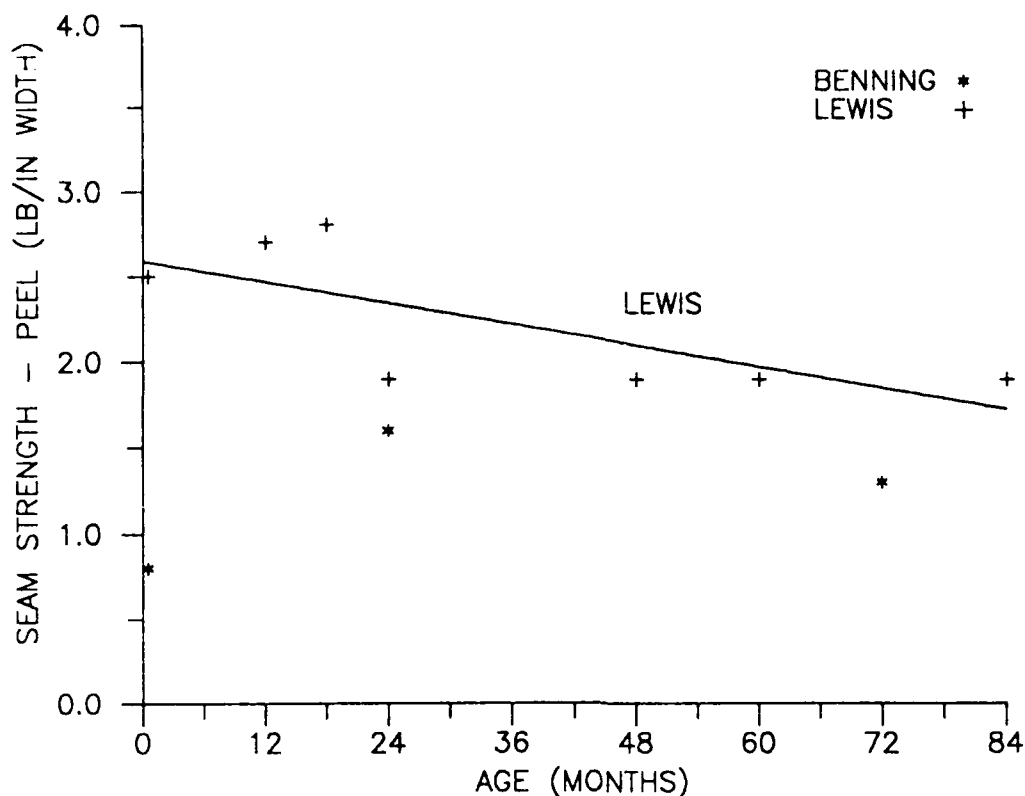


Figure 13. EPDM seam strength - peel.

PUF Roofing Property Changes

Initial Foam and Coating Properties

The initial values of the PUF properties (Table 8) reflect the differences between the products of two manufacturers. Densities of the foams were within the specified range. Closed-cell content exceeded the 90 percent value normally expected for sprayed PUF within the specified density range.¹⁰ Compressive strengths of the foam at Fort Benning exceeded the specified value of 40 psi, but the foam at Fort Lewis, with a minimum compressive strength of 35 psi, did not meet specifications. Neither foam met the specified tensile properties, but the higher tensile strength at Fort Benning indicates better interlayer adhesion than at Fort Lewis. In general, the polyurethane foam at Fort Lewis was found to be slightly different in cell structure and material composition from the foam at Fort Benning. This difference is indicated by lower strength, higher water vapor transmission, and greater dimension change.

Dimensional stability values are reported by the manufacturers as the percent change in linear dimension in the direction of foam rise. The samples from the field were allowed to expand unrestrained. Linear dimensional stability values in the direction of rise were comparable to those claimed by the manufacturer of the foam used at Fort Lewis.

¹⁰ R.L. Alumbaugh, S.R. Conklin, and D.A. Zarate, *Preliminary Guidelines for Maintenance of Polyurethane Foam (PUF) Roofing Systems*, Technical Note N1691 (U.S. Naval Civil Engineering Laboratory, March 1984).

Table 8
Initial Properties of PUF Roofing Materials

Property			Specified Value	Test Method		Fort Benning	Fort Lewis	
Density (lb/cu ft)			2.7 - 3.5	ASTM D 1622	Average Range	2.87 2.77 to 3.04	3.07 2.89 to 3.31	
Compressive strength (lb/sq in.)			40 min	ASTM D 1621	Average Range	53 44 to 58	39 35 to 41	
Tensile interlaminar strength (lb/sq in.)				USBR	Average Range	78 69 to 89	55 42 to 64	
Water absorption (g/m ² surface area)				ASTM D 2842	Average Range	48 43 to 53	49 46 to 54	
Foam water vapor transmission (perms)				ASTM C 355	Average Range	1.05 1.04 to 1.06	1.28 0.85 to 1.65	
Closed cell content of foam (percent)			Corrected for cell size	ASTM D 2856	Average Range	97.0 96.3 to 97.5	96.0 95.4 to 98.4	
			Uncorrected		Average Range	92.1 91.8 to 92.4	91.4 90.3 to 91.9	
Dimensional stability of foam (percent change in linear dimension)	Perpendicular to rise 30 percent RH	1 day	ASTM D 2126	Average Range	0.0 -0.42 to +0.48	+0.56 0.10 to 1.23		
		7 days		Average Range	+0.39 -0.06 to +1.13	+1.19 0.59 to 1.74		
		14 days		Average Range	+0.40 -0.12 to +0.96	+1.13 0.38 to 1.45		
		1 day		Average Range	+0.11 -0.18 to +0.36	-0.24 -0.28 to -0.20		
		7 days		Average Range	0.0 -0.30 to +0.12	-0.25 -0.39 to -0.10		
		14 days		Average Range	-0.16 -0.50 to +0.06	-0.03 -0.39 to +0.34		
	Perpendicular to rise 100 percent RH	1 day	Benning/Lewis	Average Range	6.74 4.76 to 7.79	19.52 19.26 to 19.65		
		7 days		Average Range	7.89 5.78 to 9.32	21.40 20.12 to 22.38		
		14 days		Average Range	8.27 6.13 to 9.61	16.48 14.77 to 17.83		
		1 day		Average Range	0.89 0.53 to 1.25	12.14 11.61 to 12.67		
		7 days		Average Range	0.88 0.77 to 1.07	13.50 11.86 to 15.13		
		14 days		Average Range	0.97 0.71 to 1.24	7.50 6.22 to 8.77		
	Parallel to rise 100 percent RH	1 day	Benning/Lewis	Average Range	30 20 to 40	20 10 to 25		
		7 days		Average Range	68 54 to 82	65 No break at 1/2-in. deflection		
	Foaming thickness (in.)				USBR	Average Range	79 72 to 85	140 120 to 192
	Foaming brittle temperature (°F)			Coldest available to temperature shown	ASTM D 2137 Typical		210 194 to 225	650 623 to 675
	Indentation strength (lb/sq in.)			Yield	USBR	Average Range	2.2 2.0 to 2.4	1.6 0.8 to 2.4
	Coating break				USBR	Average Range	160 123 to 192	174 157 to 192
Impact strength (grams)			Top	USBR	Average Range	-189 -190 to -188	+51 50 to 52	
			Base				-67 -69 to -65	
Foaming vapor transmission, perms			3.5 max	ASTM E 96 Procedure B	Average Range	2.2 2.0 to 2.4	1.6 0.8 to 2.4	
Foaming adhesion, lb/sq in.				NCEL	Average Range	160 123 to 192	174 157 to 192	
Foaming glass transition, °F			Top	ASTM D 3418	Average Range	-189 -190 to -188	+51 50 to 52	
			Base				-67 -69 to -65	

Table 8 (Cont'd)

Property	Specified Value		Test Method		Fort Benning	Fort Lewis
Parallel to rise 100 percent RH	1 day	Benning/Lewis		Average Range	0.89 0.53 to 1.25	12.14 11.61 to 12.67
	7 days			Average Range	0.88 0.77 to 1.07	13.50 11.86 to 15.13
	14 days	8/7		Average Range	0.97 0.71 to 1.24	7.50 6.22 to 8.77
Coating thickness (mils)			USBR	Average Range	30 20 to 40	20 10 to 25
Coating brittle temperature (°F)		Coldest available temperature shown	ASTM D 2137 Typical		Below -104	Below -95
Indentation strength (lb/sq in.)	Yield		USBR Range	Average 46 to 82	68 54 to 75	65
	Coating break			Average Range 79	79 72 to 85	No break at 1/2-in. deflection
Impact strength (grams)	Top		USBR	Average Range	210 194 to 225	140 120 to 192
	Base					650 623 to 675
Coating vapor transmission, perms		3.5 max	ASTM E 96 Procedure B	Average Range	2.2 2.0 to 2.4	1.6 0.8 to 2.4
Coating adhesion, lb/sq in.			NCEL	Average Range	160 123 to 192	174 157 to 192
Coating glass transition, °F	Top		ASTM D 3418	Average Range	-189 -190 to -188	+51 50 to 52
	Base					-67 -69 to -65

For the coatings, the only values specified were minimum thickness and maximum perm rating. The variation in thicknesses cannot be attributed only to foam surface texture, since the foam at Fort Lewis had a smoother surface than at Fort Benning, and the coating at Fort Benning met the specified minimum thickness. Application technique undoubtedly influenced the results. Both coatings met the specified water vapor transmission requirements.

Measured and advertised properties for the coatings could not be compared. Since coating thicknesses were so varied for any given sample, determination of tensile properties would be meaningless. The manufacturers do not publish the brittle temperatures of their products, so the determination of this property was for initial characterization only, as was the glass transition temperature. It should be repeated that the glass transition temperature is not the same as the brittle temperature, but is a temperature range in which heat is absorbed as the material undergoes a phase change. This difference is readily apparent from an inspection of data in the various tables. In keeping with the purposes and financial constraints of the test program, it was felt that only physical properties of the coating would be significant, so the tensile (mechanical) properties were not determined.

Changes in PUF Roofing Properties Over Time

It must be emphasized that PUF, as used in liquid-applied roofing, is manufactured onsite, under ambient atmospheric conditions, and not within the enclosed space of a factory under controlled conditions. Trends, therefore, become more important than singularities that may result from a change in any one of many localized conditions.

The initial and aged characteristics for the two PUF roofs can be found in Tables 9 and 10. The compressive strength (Figure 14) has shown a slight increase with time from the initial value at both locations, each staying near or above the required minimum of 40 psi. Compressive strength is an important property of the foam, as it is the one property which most resists traffic on the roof. The foam should be capable of bearing all anticipated traffic loads throughout its life. It is impossible to extrapolate the curves into the future, as more data would be required to accurately establish the trends. Tensile interlaminar strength decreased at both sites (Figure 15). The loss of tensile strength in the foam at Fort Lewis was more rapid, indicating that the specific foam used there loses its ability to adhere to itself, leading to the possibility of future separation of the layers.

Figure 16 shows the densities of foam samples. Recommended minimum density is 2.5 lb/cu ft. This is to ensure minimum compressive strength requirements of a properly mixed spray. The foam density at Fort Lewis has remained relatively unchanged. However, at Fort Benning, the density has shown a 28 percent increase after the initial sampling.

Water absorption of the foam at Fort Benning (Figure 17) remained steady, staying below 60 g/m² through 7 years. At Fort Lewis the water absorption remained at approximately its initial value for 4 years and then showed a significant increase during the last 2 years.

For the same reasons explained for the water vapor transmission and glass transition temperature testing of the EPDM roofs, these same tests were discontinued for PUF after the first 2-1/2 years. During the annual visual inspections, it was observed that the granules were becoming dislodged, with many bare areas of coating appearing.

Table 9

**PUF Roofing--Physical Properties for Initial and Aged Characteristics
Fort Benning**

PROPERTY	TEST METHOD	AGE (IN MONTHS)							
		0	12	18	24	30	48	72	84
DENSITY (LB/CU FT)	ASTM D 1622	RANGE 2.77 TO 3.04	3.16 TO 3.81	3.33 TO 3.37	3.36 TO 3.45	3.11 TO 3.71	3.53 TO 3.80	3.51 TO 3.61	1.78 TO 1.84
COMPRESSIVE STRENGTH (LB/SQ IN)	ASTM D 1621	AVERAGE 2.87	3.45	3.50	3.38	3.46	3.67	3.55	1.81
		RANGE 44 TO 58	68 TO 76	53 TO 63	34 TO 63	48 TO 64	44 TO 74	38 TO 72	25 TO 32
INDENTATION STRENGTH (LB/SQ IN)	USBR	AVERAGE 53	71	59	54	59	64	58	30
		RANGE 46 TO 82	72 TO 111	97 TO 104	80 TO 98	71 TO 102	---	---	150 TO 161
IMPACT STRENGTH (GRAMS)	USBR	AVERAGE 68	91	100	90	89	82	85	158
		RANGE 194 TO 225	430 TO 730	260 TO 500	330 TO 560	400 TO 440	---	---	---
TENSILE INTERLAMINAR STRENGTH (LB/SQ IN)	USBR	AVERAGE 210	535	394	453	420	499	499	281
		RANGE 69 TO 89	18 TO 68	24 TO 100	44 TO 89	36 TO 75	48 TO 57	58 TO 61	18 TO 37
WATER ABSORPTION (G/SQ METER)	ASTM D 2842	AVERAGE 78	42	67	60	54	53	59	26
		RANGE 43 TO 53	51 TO 63	42 TO 51	43 TO 53	45 TO 49	---	---	---
COATING VAPOR TRANSMISSION (PERMS)	ASTM E96 PROCEDURE B	AVERAGE 48	57	47	48	47	---	34	59
		RANGE 2.0 TO 2.4	1.3 TO 2.9	1.9 TO 2.3	---	1.1 TO 1.6	NOT TESTED	NOT TESTED	NOT TESTED
COATING ADHESION (LB/SQ IN)	NCEL	AVERAGE 123 TO 192	2.0	2.1	---	1.3	---	---	---
		RANGE 123 TO 192	83 TO 184	74 TO 158	105 TO 124	115 TO 120	---	---	---
COATING GLASS TRANSITION (°F)	ASTM D 3418	AVERAGE 160	130	111	115	118	70	109	94
		RANGE -190 TO -188	-187 TO -195	-186 TO -184	-187 TO -185	-184 TO -182	NOT TESTED	NOT TESTED	NOT TESTED
		AVERAGE -189	-186	-185	-186	-183	---	---	---

Table 10

PUF Roofing--Physical Properties for Initial and Aged Characteristics
Fort Lewis

PROPERTY	TEST METHOD	AGE IN MONTHS							
		0	12	18	24	48	60	84	
DENSITY (LB/CU FT)	ASTM D 1622	RANGE 2.89 TO 3.31	2.89 TO 3.30	2.93 TO 3.31	2.73 TO 3.23	2.84 TO 2.87	3.00 TO 3.40	1.61 TO 1.69	
	AVERAGE	3.07	3.05	3.05	2.94	2.85	3.11	1.65	
COMPRESSIVE STRENGTH (LB/SQ IN)	ASTM D 1621	RANGE 35 TO 41	38 TO 43	45 TO 54	36 TO 48	37 TO 60	37 TO 48	21 TO 30	
	AVERAGE	39	40	50	38	49	44	26	
INDENTATION STRENGTH (LB/SQ IN)	USBR	RANGE 54 TO 75	56 TO 65	72 TO 83	58 TO 73	---	---	141 TO 160	
	AVERAGE	65	60	80	65	80	78	150	
IMPACT STRENGTH (GRAMS)	USBR	RANGE 623 TO 675	140 TO 460	235 TO 435	270 TO 400	---	---	---	
	AVERAGE	650	323	320	335	321	499	184	
TENSILE INTERLAMINAR STRENGTH (LB/SQ IN)	USBR	RANGE ---	48 TO 87	76 TO 87	78 TO 83	55 TO 64	50 TO 58	23 TO 35	
	AVERAGE	---	72	81	81	59	54	29	
WATER ABSORPTION (G/SQ METER)	ASTM D 2842	RANGE 45 TO 54	30 TO 43	41 TO 52	41 TO 46	---	---	378 TO 1006	
	AVERAGE	49	36	47	44	52	402	737	
COATING VAPOR TRANSMISSION (PERMS)	ASTM E 96 PROCEDURE B	RANGE 0.8 TO 2.4	---	---	1.1 TO 1.5	---	---	---	
	AVERAGE	1.6	---	---	1.3	---	---	---	
COATING ADHESION (LB/SQ IN)	NCEL	RANGE 157 TO 192	170 TO 209	132 TO 166	150 TO 186	---	---	---	
	AVERAGE	174	190	150	168	50	125	138	
COATING GLASS TRANSITION (°F)	ASTM D 3418	RANGE -69 TO -65	-65 TO -63	-69 TO -66	---	---	---	---	
	AVERAGE	-67	-64	-68	---	---	---	---	

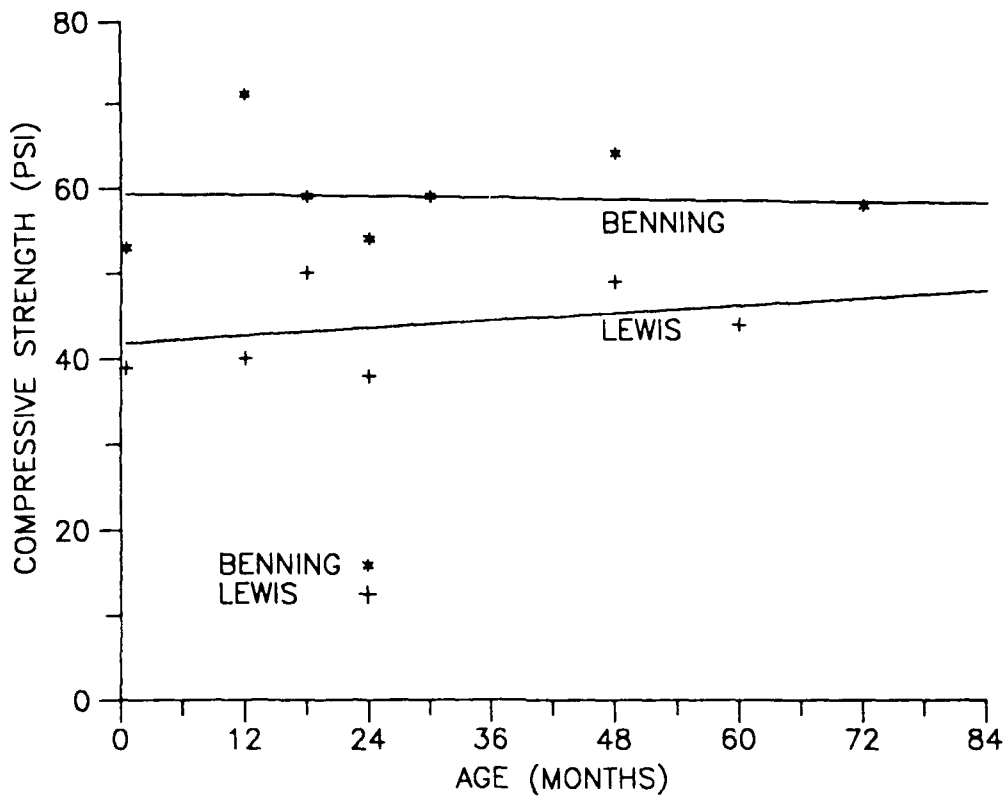


Figure 14. PUF compressive strength.

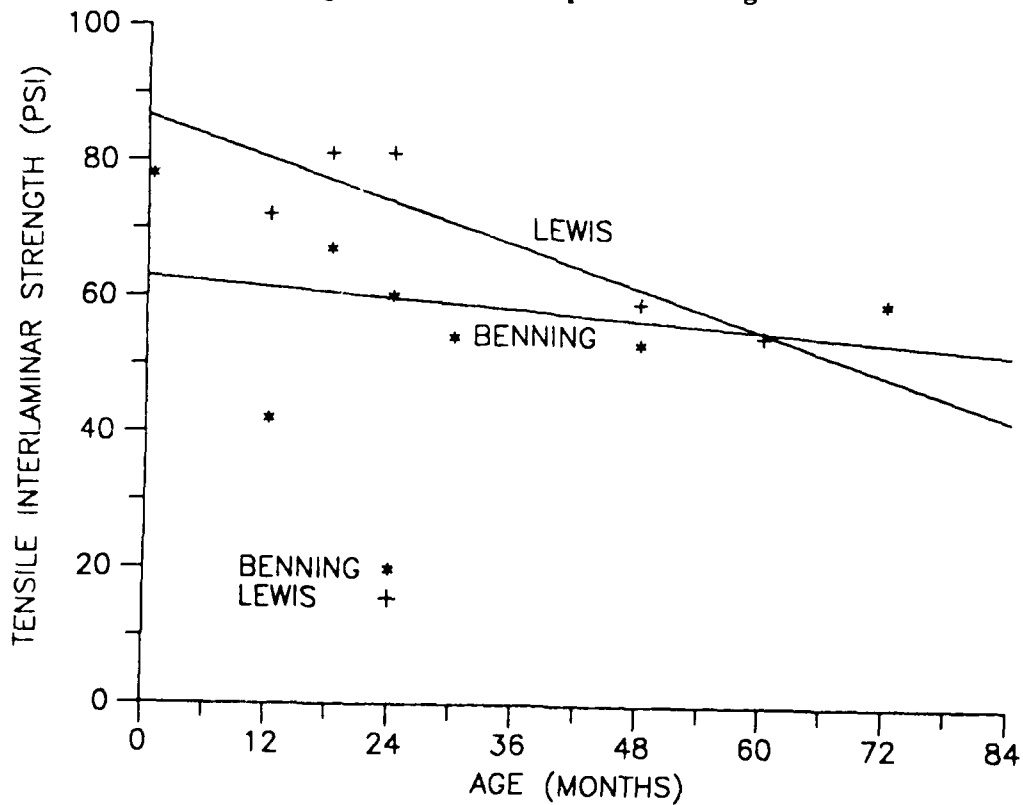


Figure 15. PUF tensile strength - interlaminar.

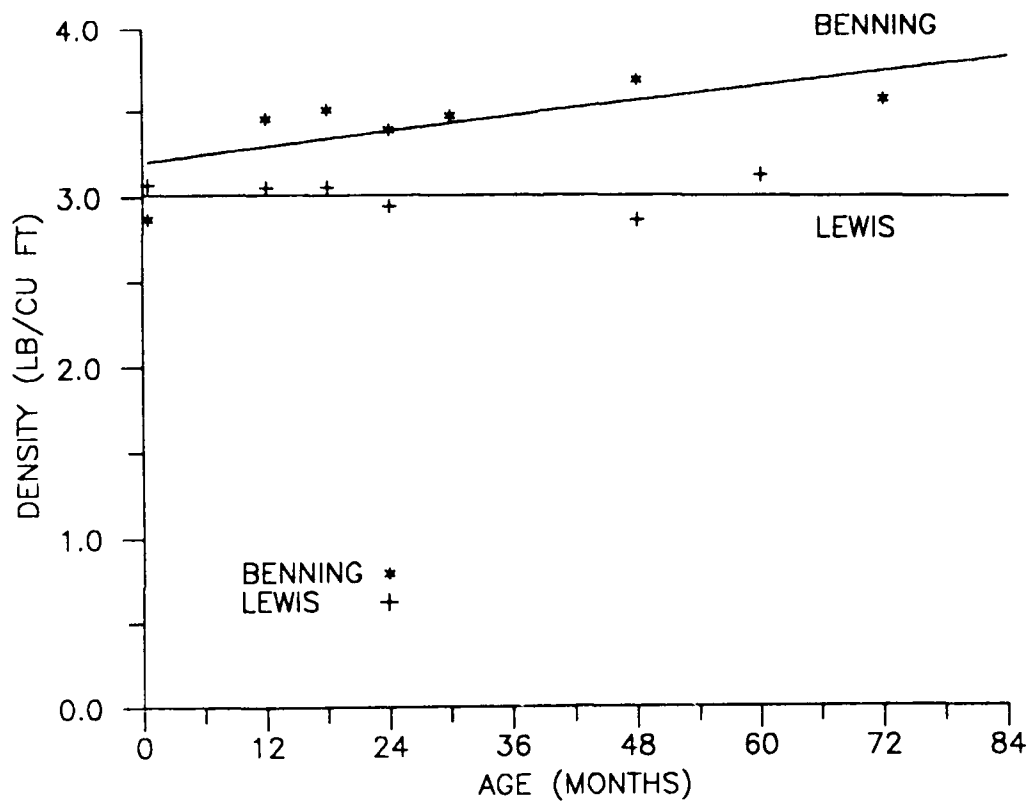


Figure 16. PUF density.

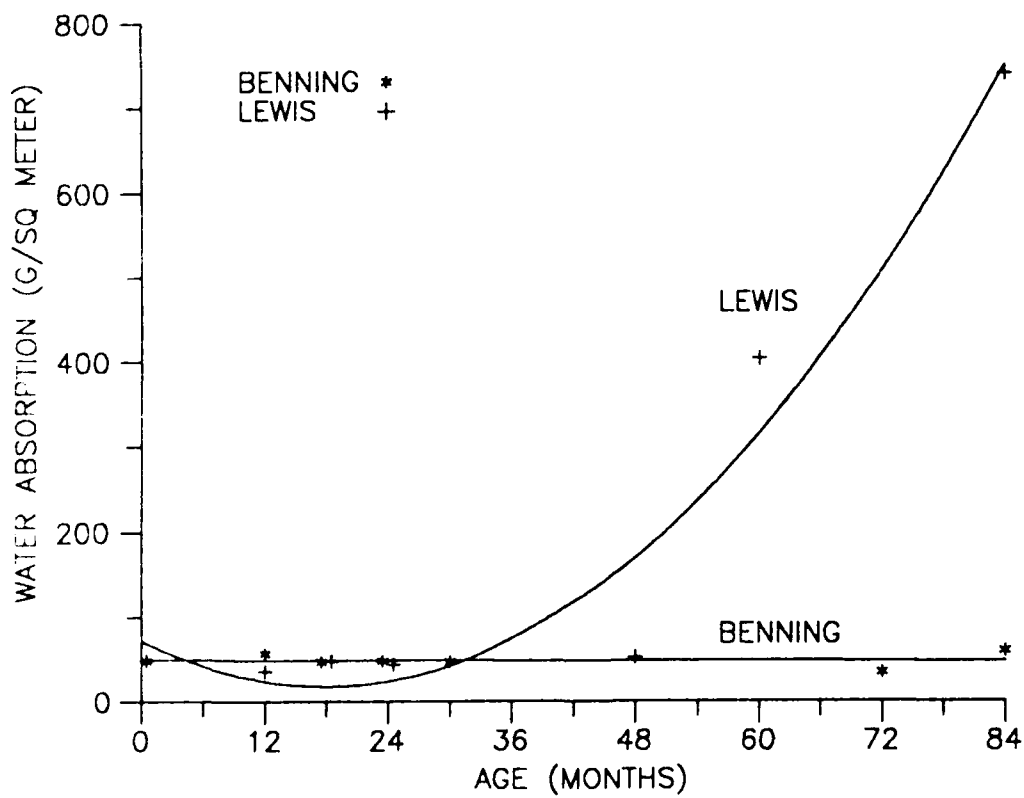


Figure 17. PUF water absorption.

Figures 18 through 20 outline changes of foam and coating assembly properties. Impact and indentation properties improved over time as coating adhesion declined. Impact strength increased at about the same rate at Fort Benning and Fort Lewis. The rate of increase in indentation strength was slightly greater at Fort Lewis. At both sites, the coating adhesion has shown a large decrease. Despite this degradation, visual inspections have not shown any significant occurrences of blisters within the foam/coating interface or peeling of the coating.

Significance of Data

EPDM

The collection and analysis of roof temperatures and weather conditions is part of the overall study to evaluate alternative roofing systems. How these roof systems will age (i.e., what changes will occur in their physical characteristics over time) is of great concern to this program. Tests performed by others¹¹ indicate that the EPDM roof materials display reduced elongation properties, increased tensile strength, and increased hardness after accelerated aging. Test results of the physical characteristics of the EPDM roofs at Forts Lewis and Benning agree with the elongation and hardness changes, but disagree with tensile strength changes. There was an initial increase in tensile strength properties after a 6-month exposure at Fort Benning, but the tests during the last 7 years of exposure indicate a gradual return to near the original levels. At Fort Lewis, a small increase was evident after a 12-month exposure, but this was followed by a decline similar to that at Fort Benning.

Long term exposure has induced property changes which in some cases were different from those anticipated in the previous report.¹² It is now apparent that EPDM ages more rapidly under stronger solar exposure, as is shown by the property changes at Fort Benning. Decreases in tensile strength and elongation, and increases in hardness and water absorption all point to solar-induced degradation. These data, although significant in understanding the property changes, should not necessarily affect the longevity of the membrane itself.

PUF

The physical properties of PUF have also been tested on samples removed from roofs at Forts Lewis and Benning. Tests of density, compressive strength, interlaminar bond strength, and water absorption show both negative and positive changes. The only possibly significant change appears to be at Fort Lewis, where interlaminar bond strength declined significantly after 2 years and water absorption increased significantly after 4 years. Average coating adhesion values of 160 to 174 lb/sq in. at the two sites have declined to average values of 94 to 138 lb/sq in. over the 7-year test period.

Degradation of the PUF roof is probably not related to temperature or exposure, but most likely is a direct result either of the application problems encountered by the contractor, the formulation of the resins by the manufacturer, the expected deterioration of the coating with time, or a combination of these.

¹¹ R. Dupuis, et al.

¹² M.J. Rosenfield, September 1984.

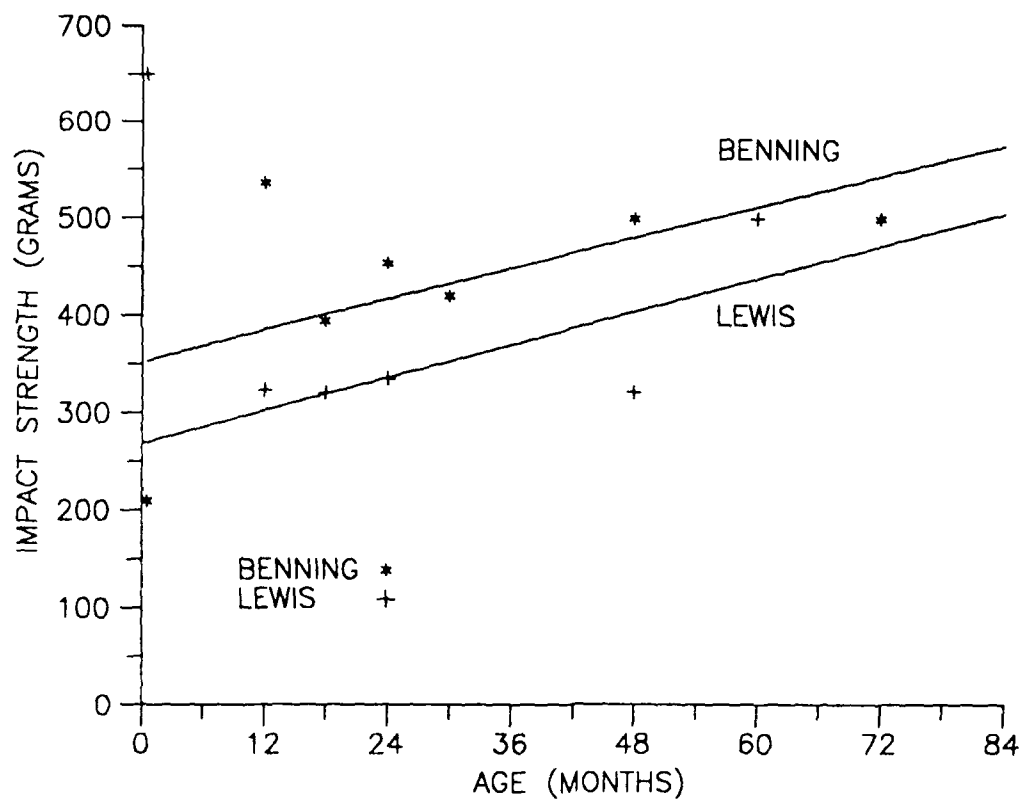


Figure 18. PUF impact strength.

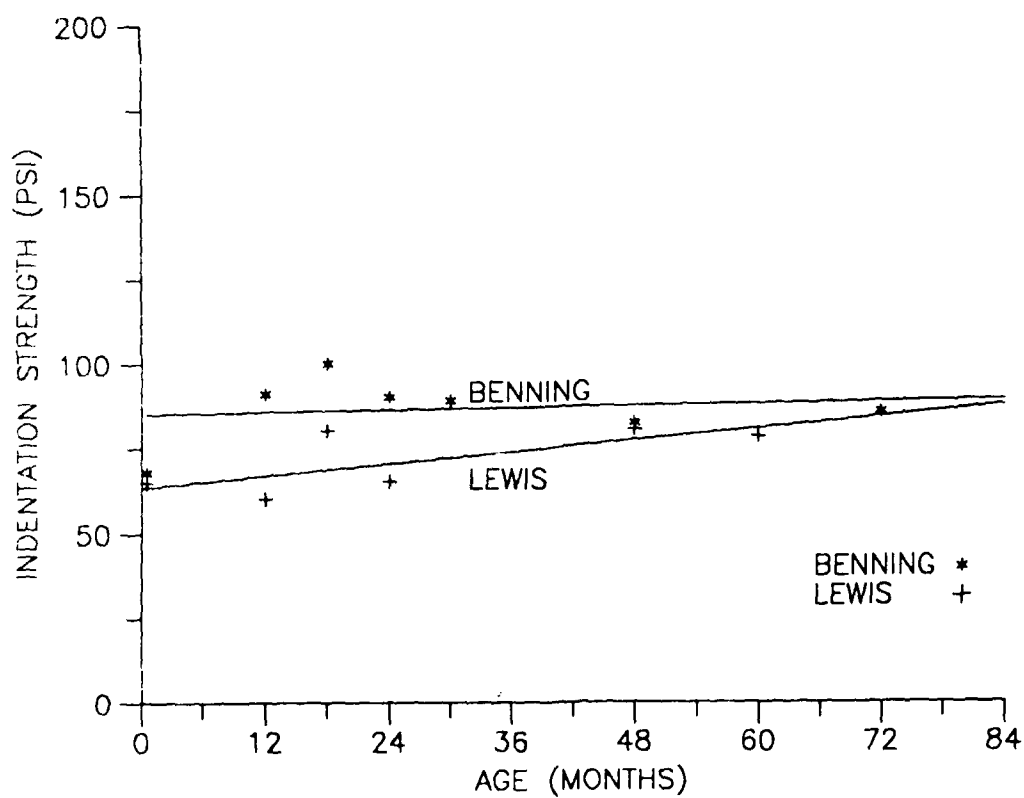


Figure 19. PUF indentation strength.

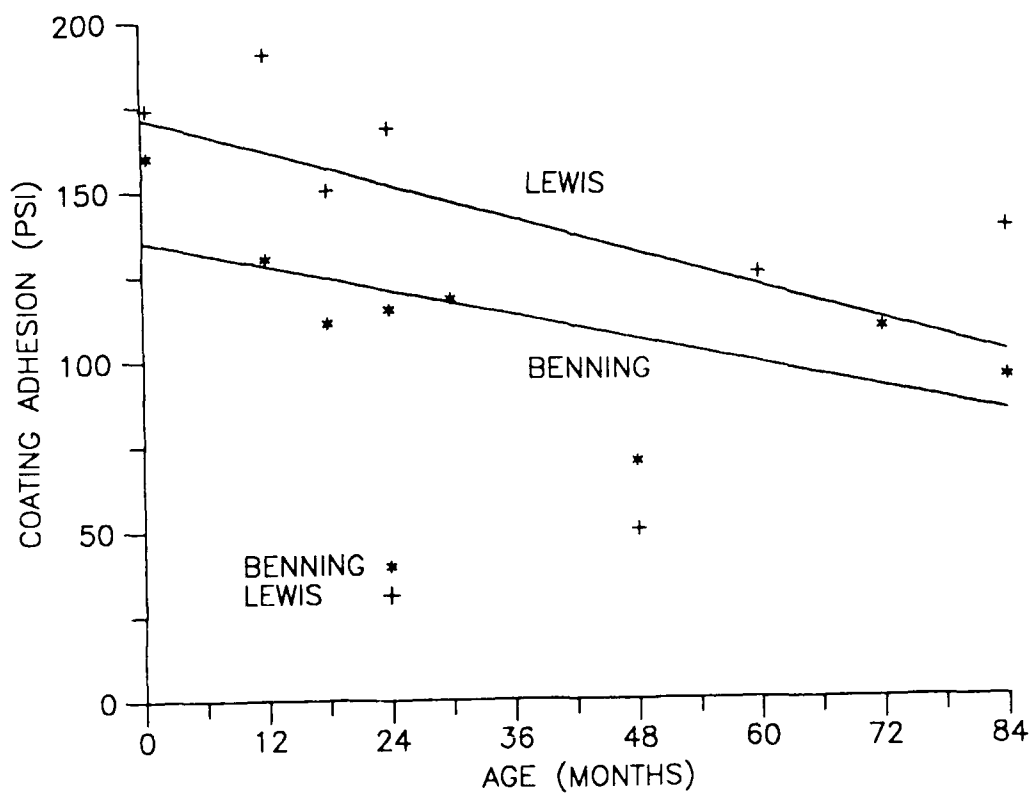


Figure 20. PUF coating adhesion.

4 RESULTS OF VISUAL OBSERVATIONS

Each roof was inspected annually as part of the evaluation process. During each inspection, the roof was carefully checked for visible signs of deterioration, giving special attention to the patches where samples for testing had been removed, as well as to flashings and indications of maintenance or repair.

First Annual Inspections - July 1981

The first inspections indicated that problems were already occurring where samples had been taken and repairs made. On the EPDM roof at Fort Benning, the membrane was generally sound, but some problems were appearing. Picture framing at the insulation joints was widespread. A few very small blisters were seen, but were apparently some wrinkles that had occurred during membrane application. The serious problems were with the repairs where samples had been taken. The first sample patches, at 6 months, were well done and the patches were all sound. The second sample patches, at 1 year, required immediate attention. They were still adhered to the underlying insulation, but had become delaminated from the roof membrane. Through later investigation and interviews with the Directorate of Engineering and Housing (DEH) maintenance personnel, it was learned that these repairs were performed in-house using whatever adhesive they could obtain. It should be noted that EPDM adhesive has a limited shelf life, and the EPDM manufacturers will not distribute materials unless the buyer is an authorized applicator of their EPDM system. In this case, the DEH had no certified personnel and could not obtain EPDM adhesive. It is suspected that the adhesive designed to attach the membrane to the substrate was erroneously used to adhere the patches, accounting for their premature failure. Fort Benning was advised to completely remove them and replace them with new material, taking care to remove all talc and roughen both contact surfaces with sandpaper. It was also suggested that repairs be made in the morning while the temperature was still cool.

At Fort Lewis, the EPDM roof also showed some picture framing. Seam sealant along the field seams was beginning to crack, but this was not considered serious, as the sealant is only temporary while the seam adhesive cures. So far, only the 6-month samples had been taken. One patch where a sample had been cut contained a small unsealed portion. The most serious problem was some blistering above the nail heads on the transverse nailers that divided the roof into 1600-sq ft sections. The manufacturer of the roof membrane was contacted and recommended a repair procedure.

On the PUF roof at Fort Benning, loose granules were collecting in low spots, leaving some high areas bare of granules. When these loose granules were brushed aside, it was observed that there were no embedded granules on the surface of the coating. This condition suggested that the coating had already cured somewhat when the granules were applied, leading to a loss of embedment or adhesion. Where samples had been removed and the holes patched, some of the newly applied foam had not been coated at all and was disintegrating.

On the PUF roof at Fort Lewis, granules were also coming loose, and were collecting at and washing down the drains. It was also observed that the granules had not been applied evenly during construction, as alternating bare and granulated streaks were evident over the entire roof area. Patches where samples had been taken were made well.

Second Annual Inspections - June 1982

The 1982 inspections revealed that the fields of all the roof membranes were in very good condition, but problems with the patches where samples had been cut were still evident. At Fort Benning, the poorly adhered EPDM patches seen the previous year had been repaired using improper procedures and materials again, but one of the original ones was now peeling off. Also, cracked seam sealant was now seen, as it was at Fort Lewis. Insulation under some of the patches felt soft, but did not seem to be wet, so this was not considered serious.

At Fort Lewis, the EPDM roof still had tiny blisters above the nail heads, with no evidence yet of any attempts at repair. The sample patches made since the previous year had been repaired better than before, and all were now in excellent condition. The contractor would have to be called back to repair a fishmouth in one of the lap joints that had developed during the year. The most serious problem now apparent had nothing to do with the roof itself, although it affected the roof. The building is adjacent to a large, dense thicket of pine trees, and the dead needles and other debris from those trees was now clogging all the drains. This indicated a need for regular maintenance, which was discussed with the Fort Lewis staff.

The PUF roof at Fort Benning was in excellent condition, except for further erosion of the granules. The poor conditions noted in the patches the previous year had been corrected, and the recent sample cuts had been repaired satisfactorily. However, the samples themselves were too small for proper testing, so the proper procedure for taking adequately sized samples was discussed with the shop supervisor.

The PUF roof at Fort Lewis was also in excellent condition, except that as at Fort Benning, granule erosion was more evident than the year before. On one of the more recent patches, the coating could be peeled off easily, indicating a need for more careful repair of the surface. Flashing around one steam vent had broken and was badly deteriorated. Expansion and contraction of this pipe had not been considered during design. This vent was the most active one in the building, cycling frequently between hot and cold. This indicated a need for careful study of methods of flashing pipes that cycle between hot and cold so as to prevent the entry of water and still permit expansion and contraction of the pipe. Two possible methods were offered to the Fort Lewis staff. One was from a draft of a Navy guide specification. The other was a detail suggested in a publication of the Urethane Foam Contractors Association.

Third Annual Inspections - June 1983

All the failing EPDM patches at Fort Benning, except one, had been repaired and sealed with lap sealant. The one exception exhibited three distinct layers: the field membrane on the bottom, the patch on the top, and the adhesive (whatever it was) as a separate sheet between the two, not adhered to either one. It is very likely that all of these repair patches were improperly made and hidden by the lap sealant around the edges of the patches.

At Fort Lewis, the tiny blisters over the nail heads, visible at each previous inspection, had been repaired as recommended by the manufacturer, but had reappeared. The membrane had become unbonded from the insulation around one of the drains, but was still watertight. The fishmouth in the seam that was noticed during the previous inspection had not been repaired, and the underlying insulation was wet. The picture framing was more pronounced than observed during the 1981 inspection, but this apparently had no adverse effect on the roof membrane. The building occupants complained of a leak at one of the exhaust fans. Inspection disclosed that a new indoor electrical junction box had been installed on top of

the motor flashing, and no sealant had been applied. Stains on top of the penetration cover indicated ponding of water with subsequent drainage into the building under the junction box. Although the roof drains had been cleaned since the last inspection, they had again become almost completely clogged with dirt.

The PUF roof at Fort Benning was in excellent condition except for one patch where the surface had been scratched, exposing the foam.

The PUF roof at Fort Lewis was an entirely different matter. All 20 locations where samples had been removed were now cracked around all or part of their perimeters, and 8 were so saturated with water that they squirted when stepped on. The flashing around the steam vent had been repaired and rebuilt properly, but the corners of the counterflashing around an exhaust duct penetration that had been removed and replaced, were not resealed. More granules had been displaced by wind scour, and the bare streaks were wider and more pronounced than before. It was recommended to the Fort Lewis staff that all 20 patches be removed, cleaned out, and repaired by a qualified foam applicator.

Fourth Annual Inspections - June (Fort Benning) and August (Fort Lewis) 1984

Many patches on the EPDM roof at Fort Benning were failing. All five of the most recent sample patches and one of the previous set were coming loose, and water would spurt out of one location where a field seam in the membrane was coming open. It was determined at this time to contact the manufacturer to discuss failures of the repair technique and determine if adequate repairs could be made.

The EPDM roof at Fort Lewis was essentially in excellent condition, showing much less weathering than the roof at Fort Benning. All repairs had been made properly and were well bonded. The picture framing was still not a problem, as the membrane was properly flexible at all places.

The PUF roof at Fort Benning was in excellent condition except for two small (about 6-in. diameter) blisters. The patch that was scratched the previous year had been repaired by spreading silicone sealant. More granules had been scoured off, but there was no deterioration.

At Fort Lewis, the patches on the PUF roof had all been repaired, but the coating that had been applied was too thin to be durable. Another problem appeared; the effect on a special roof of lack of knowledge by the maintenance crew of another trade. The air handling equipment had been serviced during the past year, and in removing the cover panels, the workers had allowed the corners to hit the surface of the foam hard enough to cause a number of triangular punctures. The addition of extra coating and granules around this equipment during roof construction was apparently not enough to resist this puncturing. The Fort Lewis staff was advised to cut out these punctures and caulk them with a silicone or butyl-based sealant.

Fifth Annual Inspections - March (Fort Benning) and May (Fort Lewis) 1985

At Fort Benning, the EPDM patches that had been failing previously were still bad, although the latest set was in good condition. The manufacturer made those patches with butyl-based splicing cement that had recently replaced the neoprene-based splicing cement. Instead of cleaning the surface with solvents and sandpaper, water and ordinary kitchen scouring powder applied with a plastic scouring pad were used.

At Fort Lewis, the EPDM roof remained in excellent condition. The previously unbonded section around the drain had been repaired and was well sealed. However, normal maintenance was again inadequate. Although the pine-needle debris had been cleaned away from the drains, it was left in piles on the roof instead of being removed, and would only wash over and clog the drains again.

At Fort Benning, a serious problem was becoming apparent on the PUF roof. A boiler vent pipe, previously inactive, had caused considerable damage to the surrounding foam by its expansion and contraction. There were also punctures in the roof surface where a wood hatch cover had been removed and dropped. Repair procedures for these problems were thoroughly discussed with the Fort Benning staff.

At Fort Lewis, the repairs to the PUF roof were still in good condition, but the punctures from the air handling equipment covers had been repaired by pouring some hot asphalt into them. The Fort Lewis staff was advised to watch them carefully for any signs of trouble. If any water should penetrate, they would have to be cut out and repaired by filling with a urethane sealant if small enough, or with a urethane board set in a full bed of sealant and a urethane coating applied to the surface.

In October 1985, a special trip was made to Fort Benning to observe the annual sample cutting of the EPDM roof and study a new patching method developed by the membrane manufacturer and performed by a manufacturer's representative.

Instead of cleaning the surface with solvents and sandpaper, ordinary kitchen scouring powder and water were used, applied with a plastic scouring pad. After scrubbing and flushing, the procedure was repeated until the dry membrane did not leave a black residue when rubbed with a finger. The new repair method involved a pressure-sensitive uncured material, both by itself in a roll on a release paper, and as one surface of a sheet of EPDM rubber, again on a release paper. The roll material was applied first, followed by a well-scrubbed piece of membrane. The other type was pressed into place. In both cases, seam sealant was applied to all edges after repairing the cut areas.

Sixth Annual Inspections - May 1986

At Fort Benning, the sample patches cut in October 1985 and sealed with the special tapes were still in good condition, but many other, older patches performed by in-house personnel were again failing.

The EPDM roof at Fort Lewis had some slight openings of a few seams and patches. Since the surface was still about the same as when the membrane was new, with no apparent deterioration, the Fort Lewis staff was certain that permanent repairs could be made without difficulty.

The PUF roof at Fort Benning was in excellent condition as far as the undisturbed area was concerned, but many patched areas were saturated with water where the coating had cracked and the repair foam had separated from the parent material. The damaged area around the boiler vent pipe had not been properly repaired, the coating had almost completely disappeared, and the foam was rapidly deteriorating.

At Fort Lewis, the PUF repairs that were observed the year before to be made with hot asphalt had not been corrected, but appeared to be holding well. Two other patches were failing because the granules from the original roof had not been adequately cleared away, and so prevented proper adhesion of the foam in one case and the coating in the other. Otherwise, as at Fort Benning, the undisturbed area was sound.

In December 1986, when the Fort Benning staff attempted to cut the next set of EPDM samples, they determined that there was no location left where the desired type of sample could be cut. They immediately informed USACERL of this development, and it was agreed that the sampling program would cease, but visual inspections would occur annually for the balance of the program. As there could no longer be a comparison between samples from Forts Benning and Lewis, the sampling program at Fort Lewis was also discontinued, but annual visual inspections continued.

Seventh Annual Inspections - March (Benning) and April (Lewis) - 1987

At Fort Benning, the in-house repairs to the EPDM and the repairs to the PUF roofs had become badly deteriorated. The self-stick EPDM patches applied only 17 months earlier were performing well. Several of the foam plugs in the PUF roof had split, and insulation in both roofs was saturated with water.

At Fort Lewis, only minor maintenance was needed on the EPDM roof (sweep off the dirt and debris and unblock the drains). This is a never-ending problem at Fort Lewis, because of the constant shedding of needles by the adjacent pine trees. The PUF roof, although still in good condition, now required recoating. Some punctures had been made during the previous year, and some coating was peeling from several repairs. All this would have to be removed and refoamed, loose granules swept off, loose coating removed, and new coating applied to the entire roof. It was agreed between the Fort Lewis and USACERL staffs that reapplication of granules would not be necessary.

Followup Inspection at Fort Benning - January 1989

Due to the severity of the reported problems with patching of aged EPDM, the manufacturer was contacted for advice. The manufacturer was confident in the repairability of the aged material and offered to show personnel from USACERL and Fort Benning how to make sound repairs on the roof.

Initial investigation of past patches showed most of them to be made with some unidentifiable grey adhesive between the roof and patch but not bonded to either one. There was little doubt that these patches would leak. Other patches were identified as having been made with neoprene-based seaming cement. Although these patches were probably made before the use of butyl-based adhesives in 1984, it is unknown when these patches were made and whether other patches with the neoprene-based adhesive had failed and been replaced. These patches appeared to be watertight but the peel strength was very low and it was decided to replace all of them. A third type of adhesive was the butyl rubber based splicing cement. There was no doubt that these patches were watertight. It was nearly impossible to peel the patch off by hand. Two patches were removed for samples and the others were left in place. One patch on the roof had been made with splicing tape in 1985 by the manufacturer. This patch was actually a series of overlapping strips. Removal of two strips was difficult, showing the peel strength to be good but less than with the butyl cement. A likely problem with this patch is the T-joint where three layers occur. This was actually done for experimental reasons and it should be avoided in practice.

The original seams made when the roof was placed looked adequate. Although in some locations the neoprene adhesive was weakly bonded, it still appeared watertight. Many of the old patches were not made in a permanent manner or were made with the outdated neoprene adhesive and were replaced with patches made with the butyl rubber splicing cement and silicone in-seam sealant. It is expected that the present procedure will prove to be excellent on membranes that have weathered 10 years and even much

longer. Replacement of the neoprene-based adhesive with butyl-based adhesive was a major improvement in EPDM technology.

Discussion of Visual Inspections

EPDM

Installation of EPDM fully adhered systems at Forts Lewis and Benning afforded an excellent comparison of the effect of direct exposure on the material when the same material was installed in two completely different climatic conditions. In this case, the materials were products of the same manufacturer, so it is reasonable to assume that the formulations were similar.

Throughout this study, problems in repairing the EPDM roof at Fort Benning were evident. Virtually all the problems were caused by repair procedures that were temporary at best and were not up to the standards of a professional roofer. The worst patches were made with an unidentified grey adhesive. Other improper patches were made with a lap sealant or a bonding adhesive rather than a seaming adhesive.

Patches made with proper materials were not without fault. The neoprene cement resulted in a low peel strength. Despite this, the patches did appear watertight. This is no longer of great importance because the neoprene has been replaced by butyl-based splicing cement. Peel strength for the butyl adhesive appears more than adequate for normal conditions. The membrane at Fort Benning has aged and weathered for 10 years and quality patches can still be made with the butyl-based adhesive. As with any roofing system, proper application procedures, such as avoiding T-joints, improves performance.

The biggest problem found during the visual inspections was a lack of proper repairs. One method of repairing an EPDM membrane is to contract the work to private roofers. The DEH often does not have the contracting mechanism in place to obtain these services in a timely manner. Also, there is a time lag and temporary repairs must be made until the contractor comes weeks or months later. A second method is to obtain the proper materials and do the work in house. The problem is that some manufacturers will not sell their EPDM roofing materials to roofers without factory training and certification.

PUF

PUF roofs at both Forts Benning and Lewis were repaired with varying degrees of success as the years passed. In some cases, the problems could be traced to inadequate cleaning or other surface preparation. In other cases, there was no apparent reason for failure. Due to the inadequate repairs, the PUF roof at Fort Benning was so saturated with water after 7 years that it was decided to remove it and apply a new membrane of a different type, which would not be disturbed. At Fort Lewis, the most serious deterioration was to the coating, which after 7 years was almost worn through. However, this is normal for a PUF roof coating. Wet areas and broken patches would have to be removed and refoamed before coating, but once this was accomplished the roof would remain undisturbed except for visual inspections.

Previously published maintenance and repair instructions,¹³ although complete, did not contain estimates of the expected life of a PUF roof repair, even though different foams were used for repair than

¹³ R.L. Alumbaugh, S.R. Conklin, and D.A. Zarate.

were placed originally. While it is not known for certain that incompatibility between the original and repair foams existed at Forts Benning and Lewis, it was observed in almost all cases that the repair foam ultimately became unbonded from the originally installed foam. It also made no difference whether the repairs were made by qualified contractor personnel or installation maintenance shop employees, as the long-term results were the same.

5 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

From the experiences during a 7-year period of exposure, sampling, and repairing, the following conclusions can be drawn about EPDM and PUF roofing materials.

1. The EPDM membranes on the test roofs performed satisfactorily through the 7-year period and appear to have many years of satisfactory performance left. The membrane can be repaired but this requires the proper materials and procedures as recommended by the membrane manufacturer. Care must be taken in preparing the seam area and applying the adhesives correctly.

2. The replacement of neoprene-based splicing cement with butyl-based splicing cement has improved the performance of properly made seams (especially repair seams on aged membrane) from marginal to very good.

3. Failure of PUF repairs was an unexpected and disturbing result of the test program, especially since the undisturbed areas of both roofs remained in essentially good condition. This indicates that a well-applied PUF roof should give excellent service, needing only a recoating as the original coating wears away. The tests indicated that both the urethane/Hypalon coating used at Fort Lewis and the silicone coating used at Fort Benning are good, serviceable materials, and should continue to be used.

4. Current repair techniques for PUF roofs seem to be somewhat inadequate, in light of the history of the two test roofs. The PUF seems to be dependent on compatibility of materials, although aging of the foam should not be discounted.

Recommendations

1. It is important to be committed to proper maintenance of EPDM or any roofing system, before it is used on Army facilities. For repairs to be made quickly and properly, it is recommended that DEH personnel or authorized applicators on an open-end contract be properly trained in the installation and repair techniques for each type of roofing system used on the base. In the case of EPDM, this would require personnel to take a factory training course which is available at the manufacturers' regional location or made available on post. Difficulties may arise if trained personnel quit and material problems may arise if the single-ply adhesive products exceed their shelf-life which is generally 1 year.

2. Contracts for specific repairs are necessary if personnel are not trained to make proper repairs or are unable to make the repairs for other reasons. In this case, it may be difficult to obtain timely repairs. If the roof is leaking and proper repairs cannot be obtained immediately, temporary repairs should be made as well as possible until permanent repairs can be made.

3. The current edition of CEGS 07540, which permits the use on PUF of both silicone and urethane coatings, should be expanded to include the use of a urethane/Hypalon coating as well.

4. Care must be taken during design of PUF roofs that all details take contraction and expansion into consideration, so that splits and failures will not occur when the roof is put into service.

5. Studies should be undertaken to evaluate the effect of different foam formulations and ages on the ability of newly applied foam to bond to that which is already in place, and to determine how long this bond can be expected to last.

METRIC CONVERSION TABLE

1 in.	=	2.54 cm
1 lb/cu ft	=	16.02 kg/m ³
1 lb/in.	=	0.1751 N/mm
1 lb/sq ft	=	4882 g/m ²
1 lb/sq in.	=	0.006895 MPa = 6895 N/m ²
1 mil	=	0.001 in. = 0.0254 mm
0.55 (°F - 32)	=	°C

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for

USACERL Technical Report M-90/09, "Long Term Field Test Results of Experimental EPDM and PUF Roofing," April 1990.

Delete paragraph 4. in the Conclusions section on page 45.

Change paragraph 5. in the Recommendations section on page 46 to read:

5. Studies should be undertaken to evaluate current repair procedures and determine the effect of different foam formulations and ages on the ability of newly applied foam to bond to that which is already in place, and to determine how long this bond can be expected to last.